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TREATISE ON THE THEORY OF THE CONSTRUCTION OF HELICOIDAL OBLIQUE ARCHES.*

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III.

CHAPTER V.

METHOD OF WORKING THE VOUSSOIRS AND SKEW-BACK STONES.

47. It should be observed of the several faces of a voussoir that, while its soffit face and extradosal are warped curved surfaces, the bedding surfaces are radial warped surfaces. On this account and because they are generally considerably wider than the soffit faces, the bedding courses are the most presentable for the first surfaces to be worked.

48. The curve of the templets of the intradosal and extradosal coursing joints may be obtained exactly by the method described in Article 12. In practice, however, the elliptical curve, S″3.4.5R″ (Fig. 4.), will be sufficiently exact; for when the length of the voussoir is small in comparison with the length of the whole semi helix, the curve will vary but slightly from this elliptical curve. Very sharp oblique arches of small diameter have been successfully built, where this curve has been regarded as circular arcts, the method of determining such circular arcts is described further on, in Articles 52 and 53. The elliptical curve is nearer the true spiral curve, of course, than the circular arcs are. But neither of these two approximate curves should be employed unless it is found, after careful comparison, not to materially depart from the true curve.

49. Let A B C D E (Fig. 19) be the elevation, and E D the plan of a templet of a soffit coursing joint, so that the curve A B C between the center lines of the iron strap, 1 and 3, will be the exact length of a voussoir soffit coursing joint. We will suppose the rules shown in Fig. 7 are the proper ones for the joint A B C at points on it equidistant apart, and that the voussoir bed warps from A H towards C J, the point J being the point in the bed farthest from a plane passing through the point A C and H. Evidently the parallel rule should be applied at A and the twist rules at B and C, so that their sides will be normal to, and their upper edges shall coincide with the sight plane 4 5.

The iron straps 1, 2 and 3 are fastened to the templet A B C D E so that their center lines here shown will be normal to the curve A B C, but their sides are normal to the plane 4 5. Their tops, like their rules, coincide with this plane 4 5. Let each of the three rules above referred to, at their intradosal points A B and C, be extended over the templet A B C D E an arm that will exactly fit into its respective strap 1, 2 or 3 (Fig. 20). Thumb screws

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in the top of iron straps will prevent the templets moving when they are once adjusted to these straps. The cross section of the parallel and twist rules should be of the form shown at K L in order that its lower edge may occupy the least space.

50. Therefore, in working the coursing bed of a voussoir, apply the soffit joint templet (Fig. 19) to the surface of the stone from which the voussoir is to be cut. It should be applied to the stone far enough from the edge of the stone to allow for the working of the soffit surface of the voussoir in the stone afterwards. When the surface of the stone has been dressed off to receive the templet let the curve A B C be marked upon it. Cut a narrow channel across the stone at A H so that its bottom surface shall exactly receive the lower edge of the parallel rule when properly adjusted in its strap 1, Fig. 20, and the soffit joint templet coincides with its curve already marked on the dressed surface of the stone. Then cut a narrow channel across the stone at B I, so that its bottom surface will exactly receive the lower edge of its twist rule, when this and the parallel rule, properly adjusted to the soffit joint templet, are applied at B I and A H respectively. In the same manner the third rule is applied at C J and the bottom of its narrow channel reduced to receive the lower edge of this twist rule. Care should be exercised in applying the twist rules that their upper edges are always in the same plane and that the upper edge of the parallel rule is in this plane, all the rules, moreover, should be normal to this plane Any number of twist rules may be thus applied. Ordinarily, a single pair of one parallel and one twist rule will be enough. The balance of the bedding surface may be reduced to the bottom surfaces of the grooves thus cut by applying a straight edge to them on lines parallel to A B and to B C.

Having thus determined the bedding surface the extradosal curve H I J may

Fig. 19

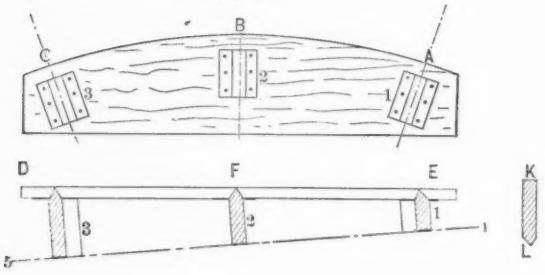


Fig. 20

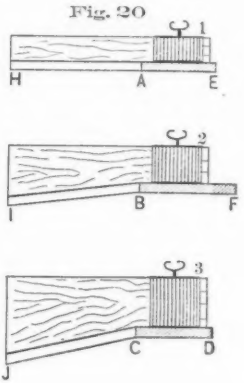
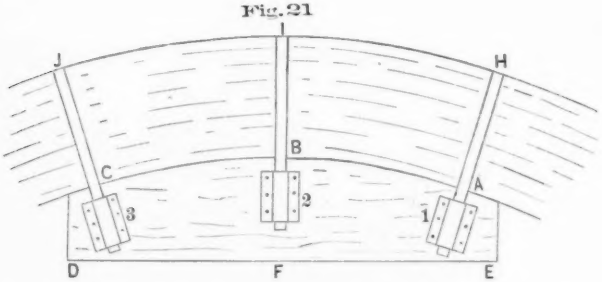


Fig. 21



be drawn upon it parallel to and distant the depth of the arch I B, Fig. 19, from the intradosal curve A B C.

51. The ordinary method of making these bedding surfaces of the voussoirs is: 1st, lay off and sink the soffit course joint A B C. Then the extradosal curve H I J is worked on the rough surface of the stone, and the parallel A H and the twist B I rule are applied normal to the curve A B C, until the upper edges are in the same plane. Then the twist rule C J is similarly applied. Thus used the rules have no arm over the soffit joint templet in the iron straps, as in Figs. 19, 20 and 21. Obviously this method of reducing these surfaces is attended with uncertain results, and that the method described in the last article is far superior to it. The method there described is true and exact, giving to all these surfaces the same warp or twist, a condition that should always be maintained, and for this reason the method of Article 50 should always be used.

51. Care should be exercised that the warp is worked in the right direction. Nor should we be deluded by the supposition that if the voussoirs are warped the wrong way, they can be used in the other end of the arch from that for which they were intended. All voussoirs in a given oblique arch have the same warp, and therefore those that are warped the wrong way cannot be used. This fact should be noted, all oblique arches here given have been *left handed* oblique arches, and the parallel and twist rules have been applied accordingly. When the oblique arch is right handed the order is reversed in their application.

52. We will now proceed to the method of working the warped soffit surfaces of the voussoirs. In Fig. 22, let 5 6 7 8 be the plan, and 5′ 6′ 7′ 8′ the development of the intrados of a voussoir, so

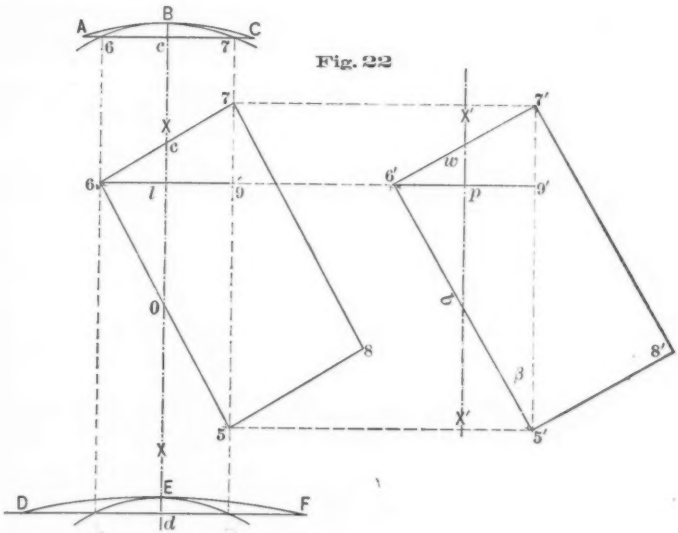


Fig. 22

that the axis X X—X′ X′ passes through the middle points of the joints 5 6—5′6′, and 6 7—6′7′, and let the curves 6 B 7 and 5 E 6 immediately above and below 5 6 7 8 each be circular arcs of the right section of the intrados. In the development the heading joint 6′7′ is perpendicular to coursing joint 5′6′ at 6′, therefore these two joints are normal to one another at the point of their intersection 6—6′, and also to the element which is common to the course helicoid and to the heading helicoid at 6—6′.

The actual lineal curves of the coursing joints 5 6—5′6′ and of the heading joints 6 7—6′7′, or their elliptical aproxi-

mates can be determined by the methods of Article 10. When regarded as arcs of the circle, their curvature may be thus obtained from Fig. 22. By construction the points 5 and 7 in the plan are in a line parallel to X X. Through 5 6 and 7 draw lines parallel to X X, producing the points 5 and 6 into the arc 5 E 6 and the points 6 and 7 into the arc 6 B 7. Draw 6 9 perpendicular to $x x$ to 9 in 5 7. Then 6 9 is equal to the chords 6 7 and 6 5 of the circular arc 6 B 7 and 5 E 6. Produce the chords 6 7 and 5 6 beyond this arc, and make A c and c C equal to 6 X or X 7, and make D d and d E equal to 6 0 or 0 5. Then A B C will be the circular curve of the heading joints 6 7—6′ 7′, and D E F will be that of the coursing joint 5 6—5′ 6′. Their middle ordinates are the same as those of the arcs 6 B 7 and 5 E 6, or both equal to B C or E D. It should be noted that while A B C and D E F are approximate values of, the chords A c C, and D d E are the actual chords of the true heading and coursing joint curves.

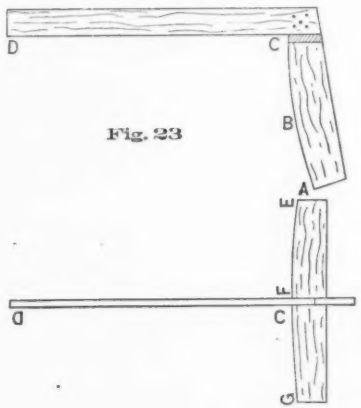


Fig. 23

53. The radii of these circular approximate curves are thus obtained. Let p be the length of each of the arcs 6 B 7 and 6 E 5 or 6 9 in the development; l their chords or 6 9 in the plan; b the breadth 5′ 6′, and w the width 6′ 7′ of the soffit development, c the chord A c C, and c' chord D d F; m the middle ordinate B c or E d; R the radius of A B C, and R′ that of D E F. Then for the given width w the axis X′X′ will pass through the middle points of w and b,

when $$b=\frac{w}{\text{tang. }\beta} \tag{19}$$

or $$p=w\text{ cos. }\beta=b\text{ sin. }\beta \tag{20}$$

whence we have

$$l=2\,r\text{ sin. }\tfrac{1}{2}\left(\frac{p}{\pi\,r}.180^\circ\right)=2\,r\text{ sin.}\left(\frac{p}{\pi\,r}.90^\circ\right) \tag{21}$$

$$m=r-\text{cos.}\left(\frac{p}{\pi r}.90^\circ\right) \tag{22}$$

in the triangle 6 7 9, $67=c$, $69=l$, and $79=7'9'=w$ sin. β,

or $$c^2=l^2+(w\text{ sin. }\beta)^2 \tag{23}$$

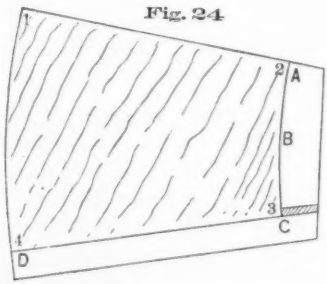
but $$\frac{c^2}{4m}=2\,\mathrm{R}-m\quad\therefore\ \mathrm{R}=\frac{c^2}{8w}-\tfrac{1}{2}m \tag{24}$$

and in the triangle 5 6 9, $56=c'$, $69=l$, and $59=b$ cos. β,

or $$(c')^2=l^2+(b\text{ cos. }\beta)^2 \tag{25}$$

and $$\mathrm{R}'=\frac{c'^2}{8w}-\tfrac{1}{2}m \tag{26}$$

Fig. 24



54. Fig. 23 is the side view and plan of the templet for the soffit face of the voussoir, or simply of the soffit face templet. The blade A B C is of the exact length and curvature of the soffit heading joint of the voussoir, and is permanently attached to the stock, so that its edge C D is normal to the curve ABC at C, and blade E F G is also normal to the stock C D at C, and its curved edge G F E is the curve of the soffit coursing joint.

55. The soffit face templet is thus applied. After the first coursing bed has been worked as described in article 50, apply the stock to it and work off the soffit face of the stone until the curve E F G coincides with the soffit coursing joint line already worked on the coursing bed,

at the same time the curve A B C is applied, and the voussoir soffit surface will be worked throughout its entire length. Then on the soffit face so worked, lay off a line parallel to its coursing joint, already obtained, and distant from it a distance equal to the curve A B C of the soffit face templet for the second coursing joint. Then the soffit face of the voussoir is determined.

56. The soffit face templet is then reversed. Its curve A B C is applied to the warped soffit and its curve E F G to the second coursing joint just obtained, and the second coursing bed is worked to the stock C D. Thus let 1 2 3 4 (Fig. 24) be the end view of a voussoir whose upper coursing bed 1 2 and soffit face 2 3 has been worked, the soffit face templet is shown applied to work the second coursing bed 3 4. The extradosal coursing joint on this second bed can be obtained in the same manner it was on the first bed, and then the back of the stone can be worked off, and the whole voussoir will be worked.

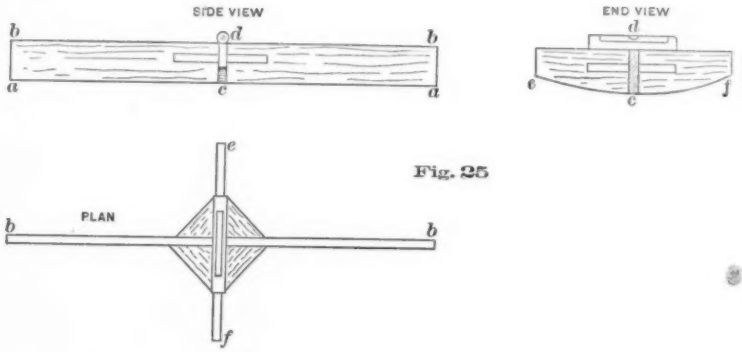


Fig. 25

ANOTHER METHOD OF WORKING THE VOUSSOIRS.

57. First work in one bed of the stone a convenient portion of the soffit cylindrical surface. This may be done by cutting into it the drafts of the arcs of 2 right sections of the soffit, and then working the face to these drafts and on lines normal to these sections. This may be done with the templet shown in Fig. 25. The two arms *a a b b* and *d e c f* are permanently secured to one another so that the parallel edges *a a* and *b b* and the plane of the arm *a a b b* are at right angles to the plane of the arm *d e c f*. The lower edges of the two arms coincide at their point of intersection, and the curve *e c f* is a circular arc of the soffit right section.

A line drawn on a cylindrical surface normal to the right section of this surface is a straight line parallel with axis, or in other words, it is an element of the cylindrical surface. If, therefore, two drafts be cut in the face of the stone to receive the lower edges of this templet, the straight draft will be an element of the cylindrical surface of which the curved draft is a right section, and if either arm be raised over its draft without departing from its plane, and the stone be worked off to receive the sweep of the other arm of the templet, the surface thus obtained will be of the soffit cylindrical surface. If the circular arm extends sufficiently on either side of the straight edge to sweep the entire soffit of a voussoir, the templet may be confined to the single movement of the arm *a a b b* over its straight draft, and this arm may be maintained within a single plane in this movement by a spirit bubble on the upper edge of *d e c f*. In working this cylindrical surface care should be taken that the straight draft should be cut deep enough that the sweep of the circular arm shall be entirely within the body of the stone. Otherwise the voussoir soffit may be deficient.

Through any convenient point A, Fig. 26, of a cylindrical surface thus worked draw an element A E. If 1 2 be the straight draft line over which the arm *a a b b* of the templet (Fig. 25) moved

to determine this surface, A E is determined by drawing a line through A parallel to 1 2.

Let A′ B′ C′ D′, Fig. 27, be the soffit development of any voussoir and let a templet of card, lead, zinc, sheet iron or other flexible material be cut exactly to its pattern, with any convenient hole *a* cut through it to show the coincidence of the line A E, Fig. 26, with it. Then apply A′ and line A′ E′ of the templet with A and A E, Fig. 26. Curve the templet exactly to coincide throughout with the worked surface (Fig. 26), and trace on the soffit edges of the voussoir as shown by dotted lines.

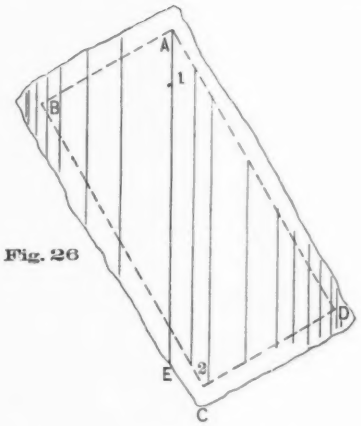


Fig. 26.

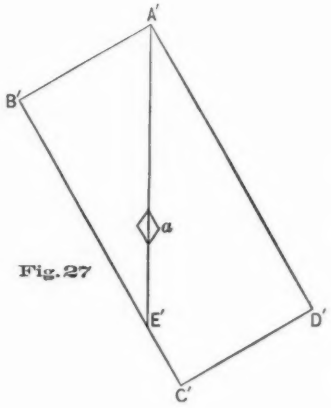


Fig. 27.

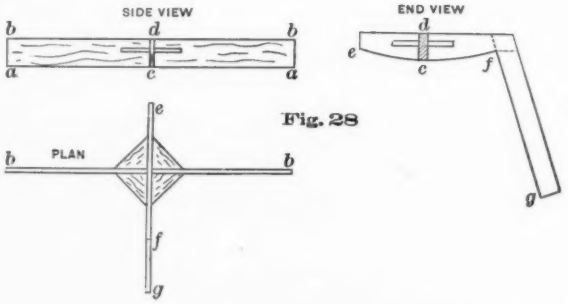


Fig. 28.

58. The templet, shown in Fig. 28, is the same as Fig. 25, except the spirit level is removed and the arm *f g* is added to it. This arm is permanently attached to and is in the same plane as the circular arm *d e c f*, and its inner edge *f g* is normal to the circular arc *e c f*. The coursing beds of the voussoirs are worked to this templet. The arms *a a b b* and *d e c f* are applied to the soffit, care being always taken that the edge *a a* always coincides with an element of the cylindrical surface. In working the bed at A D the templet is applied to the soffit and the point *f* is moved along the joint A D and the stone below is worked off to receive the arm *f g*. To work the bed below B C the templet is reversed, the point *f* moves along B C and the coursing bed below B C is worked off to receive the arm *f g*. The edge *f g*, in application, is normal to the heading joints and to the coursing joints of the soffit when the point *f* is at A, B and C the line *f g* at such points is therefore at the intersection of the heading surfaces and of the coursing beds when so applied. If, therefore, the templet be applied at A and the direction of *f g*

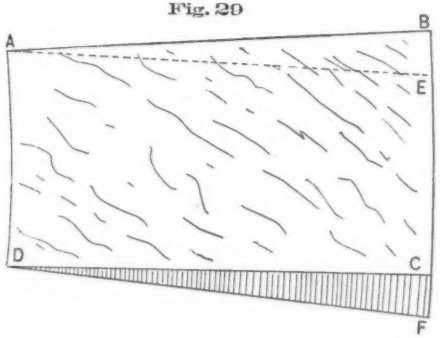
marked on the coursing bed below A D and then at B and the direction of fg worked on the bed below B C, the heading surface is determined and can be worked to the two lines thus determined and to the heading joint A B. In like manner work off the heading surface at C D.

This process has the great advantage of determining all the joints and surfaces of a voussoir with great exactness. It, however, requires great care in application, simple as is its theory. Care should be exercised, 1st, in working the soffit to true cylindrical surfaces; and 2d, in working the coursing beds for the soffit, that the templet be so applied that the lower edge of the straight edge arm always coincides with an element of the soffit.

45 be the convenient number of voussoirs for the face of the arch, then the length of the bedding joint will be $\frac{59.165}{45}=1.315$ whence for Eq. (24) R=23.07. If 3 feet is a convenient soffit length for the voussoirs their extradosal length will, Eq. (25), be 3.61. Eq. (6) gives $\Phi=37°-11\frac{1}{3}'$ or equal to β and Eqs. (4) and (5) makes the extreme warp to 0.25 or 3″. The middle ordinate of the soffit heading joint is .009, and that of soffit coursing joint is .012. The intradosal width is 1.31 and the extradosal 1.45.

60. Let Fig. 29 be an end view of a helicoidal voussoir. The waste of material will be a wedge C D E or B A F whose width is the length of the voussoir, or if the voussoir be of the warp and dimen-

Fig. 29



INCREASED COST OF WARPED SURFACES.

59. No exact rules can be given for the percentage of the waste of material in working voussoirs to helicoidal warped surfaces over that of working them to straight surfaces in right arches. For besides the diameter and obliquity of the arches this percentage is dependent upon the three dimensions of the voussoirs.

If we consider an oblique arch of ordinary diameter, but of an unusually sharp angle of obliquity, the per cent. of this waste and cost of working will, of course, be unusual. Let an oblique arch of 30 feet diameter, and of 40° obliquity be such a case, and we will suppose the arch to be 2.50 feet deep $\theta=50°$. The right semi-circumference or $\pi r=47.17$ and from eqs. (11), (13) and (14) $\beta=37°-11\frac{1}{3}'$ $\beta'=41°-31'$ and G S, Fig. 16, 59.165. Let

sions given in Article 56. This waste will be 1.03 cubic feet. The contents of the warped voussoir or its equivalent straight voussoir are 11.33 cubic feet, or the waste of material is less than $8\frac{1}{2}$ per cent., since the contents of the block from which the warped voussoir curve is 12.36 cubic feet.

Allowing $1.60 @ perch of 16 feet for quarry stone the block for the straight, and warped voussoirs will cost respectively,

	Straight.	Warped.
	$1.13	$1.24
There are $32\frac{1}{2}$ square feet dress surface in each case, which @ 12c. is	3.90	3.90
Extra on account of the warp		50
	$5.03	$5.64

Or the warped voussoirs will cost $12\frac{1}{2}$ per cent. more than the straight ones.

This per cent. in practice would be less than 10 per cent. This comparison has been made on the supposition that the block stone were quarried exactly to the given dimensions in both cases. In practice, however, they are quarried considerably larger than needed. The block stone would probably be of the same dimensions in both cases. Again, our illustration is an unusual one. In an ordinary obique arch the obliquity is much less, and the per cent. of cost would be less than 10 per cent. If the workmen are skilled in the use of the templet they will cut warped voussoirs as rapidly as straight ones, and the skill is soon acquired. The extra cost for templets is insignificant, in work of any magnitude.

SKEW-BACK VOUSSOIR ARCHES.

61. It will be observed by reference to Fig. 17 that the intradosal development of the voussoirs at the spring lines S V and G Q are right angled triangles. Let Fig. 30 be an enlarged cut of one of these triangles. Its spring line length l or C B is obtained by dividing its whole spring line G Q by the number of these triangles upon it. Draw p or A C perpendicular to l, and let the two parts of l thus divided be t and t'. The angle A B C will be equal to β the angle of the intrados, whence we obtain

$w = l \sin. \beta$ (27) $\quad b = l \cos. \beta$ (28)

$p = w \cos. \beta \quad\quad b \sin. \beta$ (29)

$t = w \sin. \beta$ (30) and $t' = b \cos. \beta$ (31)

The triangular extradosal development of these voussoirs are shown in Fig. 18. Any of these spring lines, p being an element of the intrados parallel to the axis of the arch is a straight line, and the corresponding spring line of the extrados is equal to and parallel to p. Their impost surfaces are plane surfaces. If they are constructed without being made part of the course immediately below them, they will crack off at B and C, Fig. 30, and the tendency to move over the impost will be great. But if they are made part of the course below this weakness will be overcome, and the tendency to move over the impost will be abutted by by the rising walls.

62. These skew-back voussoirs arranged as suggested by Article 57, are thus constructed. The coursing bed at A B, Fig. 30, is worked for its length A B the same manner as that of any voussoir in the body of the arch is. Let Fig. 31 be an end view of one of these skew-backs, A C G H being that of the heading surface. The line A H is normal to the soffit coursing joint of the bed just worked, and is therefore determined. Then apply the stock of the soffit face

Fig. 30

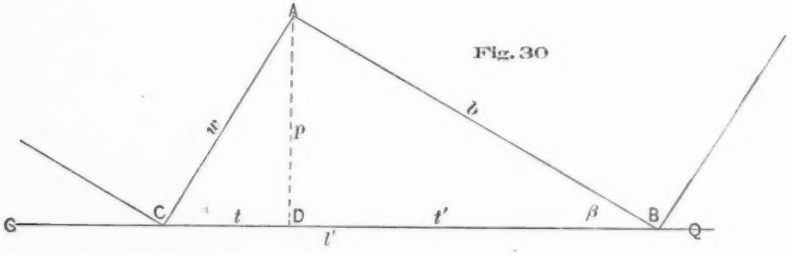
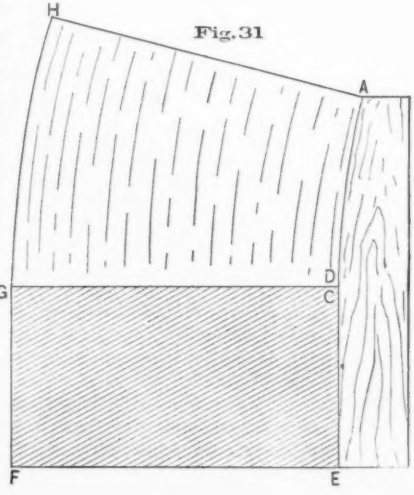


Fig. 31



templet to A H and determine C, Figs. 30 and 32, Fig. 32 being a perspective view of the worked skew-back. Work a straight line C B and let the soffit face templet be applied and the soffit between A B and B C worked. Lay off on C B C D = t, Eq. (30), and apply the curve A D of the templet A D E, Fig. 31, to the A D, Fig. 32, and work the line D E in the face of the skew-back. In the templet A D E the curve of the right section of the arch and the straight edge D E departs from a normal to this curve at D in conformity to the latter of the face of the abutment. The line B I, Fig. 32, is

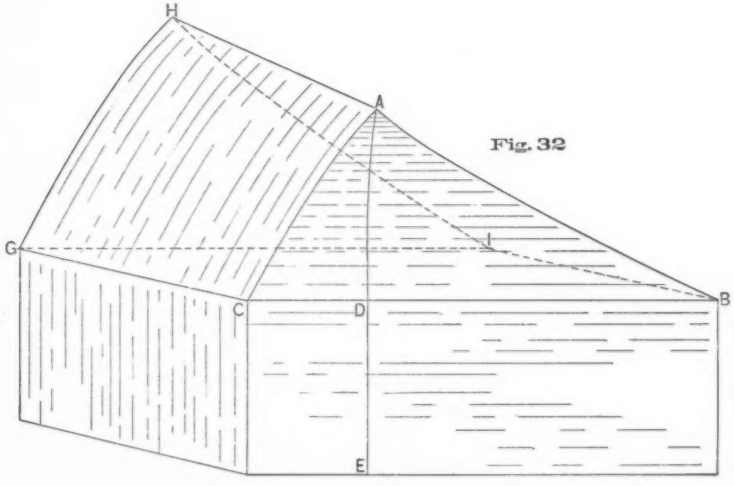


Fig. 32

normal to the curve A B and is determined in working the bed A B I H. Therefore, make C G normal to C B and parallel to I B, and work the heading surface A G by H. The face of the skew-back is then worked off on lines parallel to D E, and the bed parallel to the impost plane B C by I. When the skew-backs are then cut the stone from which they are worked may be quarried without waste of material over that of the voussoir in the body of the arch.

Chapter VI.

Method of working the ringstones, centering, &c.

Ring Stones.

63. Let Fig. 32 be the development of an arch face end of the intrados and the extrados between the axis X′X′ and their spring lines S V and R T showing the end curves X′S and X′R and the successive coursing joints of each surface. These end curves should be exactly determined by Eqs. (17) and (18) and the coursing joints by Articles 45 and 46.

Beginning at the axis X′X′ let the corresponding intradosal and extradosal surfaces of the successive courses be numbered 1, 2, 3, 4, &c., and their corresponding coursing joints, 1, 2, 3, 4, &c., as shown.

To determine the angle an end line C A of the intrados between any two coursing joints 3 and 4 makes with these joints. Through a, the point of intersection of the joint 4 with the curve X′S, draw $a\,b$ perpendicular to the joint 3. Then if A B C D, Fig. 34, be the soffit of a properly worked voussoir, at any convenient point d draw dce normal to C D or joint 4, which may be readily done with the soffit face templet, Fig. 34. Lay off ef on A B or joint 3 equal to bc, Fig. 33. If then a flexible straight edge be applied to the soffit and df drawn upon it, df will be the proper location of the end line ac, Fig. 34.

All other arch face lines of the soffit may be in a like manner determined.

64. To determine the angle the joint of any coursing bed 5 5, and of the face

of the arch makes with its soffit coursing joint, through h the joint of intersection of the intradosal joint 5 and the end curve $x's$, draw $h\,i$ in a direction perpendicular to the axis $x'x'$, and intersect the extradosal joint 5 at i. By construction h and i are the intradosal and extradosal extremities of the element of the warped

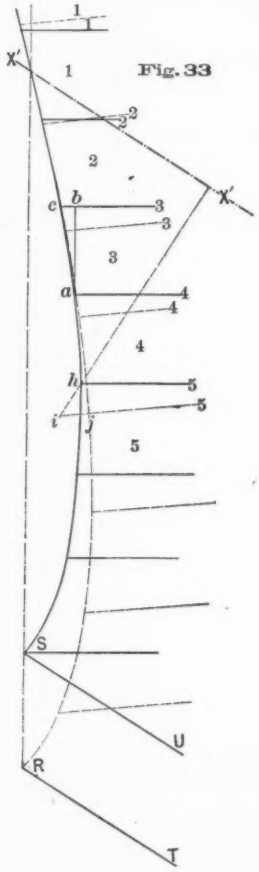


Fig. 33

coursing bed. Therefore $i\,j$ is the distance on the extradosal joint 5 that the point j of the intersection of the extradosal joint 5 and X'R, is from the extradosal extremity of the normal line to the soffit coursing joint 5.

hen if A B and C D, Fig. 35, are respectively the intradosal and extradosal joint 5 5 of the coursing bed A B C D of a properly worked voussoir, apply the soffit face templet to it at any convenient point a, and determine the normal $a\,b$ to the joint A B at a. Lay off on C D, $b\,c$ equal to $i\,j$, Fig. 29, and applying the flexible rule to the coursing bed, draw $c\,a$ from c to a, for the proper location of the arch face joint of the coursing bed 5 5, and for the courses 4 and 5.

In this and the preceding article the entire half of the two curved ends and their coursing joints have been considered, for the convenience of illustration. Such consideration is not always convenient to entertain, but the parts relating to one or more courses may be treated separately by methods that readily suggest themselves.

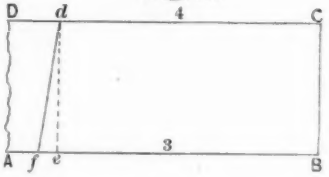


Fig. 34

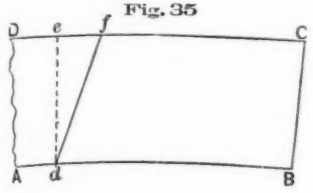


Fig. 35

CENTERING.

65. The centering ribs should be placed in planes parallel to the face of the arch, and, therefore, when so arranged will be eliptical. They are sometimes placed normal to the soffit, or made circular, when, in order to receive the arch under its acute angle, the centering has to be extended beyond the obtuse angle, and there loaded to prevent any movement in the centering when the voussoirs are set near the actual angle. Circular centering should not be employed to receive the voussoirs of an oblique arch. The ribs of the eliptical centering being parallel to the arch face, are in the planes of pressure, are easily maintained and require no more material than is necessary to receive the voussoirs.

66. The sheeting or lagging should be so put on the ribs that it will have an even and smooth surface, and that the centering will be of the exact dimensions to receive the voussoirs. When so prepared the soffit coursing joints of every course should be carefully and permanently marked upon the sheeting, as a guide for the placement of the voussoirs in the arch. The location of these joints on the centering may be determined from the development of the intrados. As the skew-back stones are generally set before the centering is, no lagging or sheeting will be required on the centering below the intradosal upper courses of the skew-back stones.

SEGMENTAL AND ELLIPTICAL ARCHES.

67. As the same principles are involved in segmental as in full semi-circular right section of a helicoidal oblique arch, no further rules are necessary for their consideration.

As in right segmental arches the axes of oblique segmental arches are in the planes of their imposts or springing surfaces, and their skew-back stones should be constructed accordingly.

Elliptical oblique arches are not recommended, both on account of their structural weakness and the difficulties involved in their construction.

THRUST OF THE ARCH.

68. The thrust of a helicoidal oblique arch being carried to the impost in lines parallel to the face of the arch causes a tendency in the arch to move outward at the acute angle of the arch, which is resisted by the friction of the coursing beds of the voussoirs. This tendency to move increases with the acuteness of the angle of obliquity, and when very acute this tendency should be resisted by properly constructed wing walls. When so constructed these arches may be constructed to any desired angle. It will, however, be a rare case where the angle of obliquity is less than 25°—the limit calculated by John Watson Buck. If he had considered the arch helicoids constructed as recomended in Article 44 the construction would have been more stable, and his limit less than 25°.*

* Helicoidal oblique arches are much more stable than that they are generally supposed to be. During the summer of 1877 the author superintended the construction of two of these arches, of 66 feet cylindrical length, 16 feet right diameter, and of 40° obliquity, each, and though placed under two tracks over which the heaviest railroad traffic passed, these arches, at this time, March, 1880, do not evince the least weakness. No extra precaution was taken to prevent the skew-back stones moving over their beds. A right arch could not have performed the work better or more satisfactorily.

THE CORRELATION OF THE DIFFERENT BRANCHES OF ELEMENTARY MATHEMATICS.

By R. B. HAYWARD, F. R. S.

From "Nature."

Among the permanent acquisitions to mathematical science secured within the last half century, within the limits of those branches with which our Association concerns itself, two (I conceive) stand out as pre-eminent in their far-reaching and all-pervading consequences.

These are the firm establishment as distinct entities of two concepts, which have been fixed for all the future of science in the terms *Energy* and *Vector*, and the development of the groups of ideas and principles which cluster around each.

The term *Energy* indeed, and the great principle of the *Conservation*, or (as I prefer with H. Spencer to call it) *Persistence*, of Energy, the establishment of which will live in the history of science as the great achievement of the central part of the nineteenth century, have a scope far beyond the purely mathematical treatment of dynamics and the allied branches of physical sciences. They, the concept and the principle, have already profoundly modified the views of the physicist as to the natural laws with which he is concerned, and are destined to form the starting-point and firm foundation for all his conquests in the future.

But no less is it true that the conception of energy, while it has naturally arisen out of the higher mathematical treatment of dynamics, has necessitated a very material recasting of that treatment in its most elementary, as well as in its more advanced, stages, if it is to bear any fruitful relation to physical science in general. This recasting of elementary dynamics, if not yet fully and satisfactorily effected in most of the text-books which still remain in use, in which the notion of energy is brought in rather as as the "purple patch" than inwoven into the whole texture of the robe in which the subject is clothed, is yet, thanks pre-eminently to the teaching of Maxwell, Thomson and Tait, and Clifford, in a fair way for being accomplished.

The influence of the conception of energy is, however, as regards mathematics, rather an influence from without than one from within its peculiar domain.

That which is strictly mathematical in the treatment of any science is not its subject-matter, but the *form* in which that subject-matter must from its nature be expressed. Mathematics, as such, is in fact *a formal* (may I not say *the* formal?) science, concerning itself with the particular matter only so far as that matter necessitates a particular form for its expression. Hence the recurrence of the same formulæ and mathematically the same propositions in different branches of science, so that, to take elementary instances, a proposition in geometry may be read off as a proposition in statics by substituting forces for lines, or the formula which determines the speed of the center of mass of two masses having different speeds is also that which determines the temperature resulting from the mixture of two masses of different temperatures.

To this *formal*, or essentially mathematical, part of the exact sciences belongs the conception of a *Vector*, or rather the group of conceptions which cluster around that term. The term itself was introduced by Hamilton in connection with his grand theory of quaternions about forty years since, but the idea had been already firmly grasped and developed so as to afford a complete explanation of the imaginary ($\sqrt{-1}$) of ordinary algebra within the twenty years preceding that epoch. In fact in the year 1845 I myself enjoyed the privilege, as a young student, of attending lectures of De Morgan on this subject, which he afterwards developed in his treatise on "Double Algebra," published in 1849. I think, however, that we may conveniently date from the introduction of "*Vector*," which is now the accepted term for any magnitude which besides numerical quantity or intensity has a definite direction in space, the definitive acquisition of this concept with all its consequences to the settled territory of mathematical science. The calculus of quaternions indeed, or that part of it which was truly original and due to the genius of Hamilton alone, involving the conceptions of the products and quotients of vectors in three-dimensional space, is doubtless beyond the range of what now can be, or within the near future is likely to be, regarded as elementary mathematics; but the notions of vector addition and subtraction and their consequences in geometry and mechanics ought assuredly to be considered as within that range, as ought also, for a complete view of ordinary algebra, vector products and quotients in one plane.

If we inquire in what manner we should expect the idea of a Vector and its attendant ideas to affect our elementary teaching, I think the answer would be that it would naturally lead to a different grouping, or arrangement in order, of the various branches taught. It would lead us to group them not according to their subject matter—arithmetic and algebra, the sciences of number, particular and general; geometry, the science of space; trigonometry, in one aspect treating space and number in combination, in another as a development of algebra; statics, dealing with forces in equilibrium; dynamics, with forces producing motion; and so on—but according to their *form*, as dependent on the nature of the magnitudes dealt with. One-dimensional magnitudes, that is, magnitudes defined by one element only, whether such as are completely defined by one element, or more complex magnitudes regarded for the moment in respect of one of their elements only, would naturally form the first stage, with subdivisions according as the treatment is purely *quantitative* or *metric*, or

scalar, that is, metric with the addition of the notion of sign or sense. Then would follow two-dimensional magnitudes, or magnitudes defined by two elements, treated with respect to both elements in subdivisions *metric* and *scalar* as in the first stage, and also finally as complete *Vectors*.

If we further inquire how far these notions have in fact affected our elementary text-books, I think we shall find that the extent to which they have done so is very small. A comparison of the text-books of the present day (I speak of them in the gross, not forgetting that there are some important exceptions) with those that were current at the time when my own mathematical studies began, an interval of some forty years, produces the impression of likeness rather than that of contrast. Changes, which are welcome improvements, have doubtless been made in matters of detail, and in various ways the paths have been smoothed for the student; but the general treatment is essentially the same, and shows very little sign of independent thought, informed by more extended views, having been exercised with regard to the old traditional modes of presenting the subject as a whole.

The algebra, for instance, of our ordinary text-books is (if I may venture to give it a nickname which every brother Johnian at any rate will understand) *heptadiabolic*,* or that whose highest outcome, in the mind of the pupil who has studied it, is the solution (so called) of a hard equation or equation problem little more in fact than a series of rules of operation, which skilfully used (and how many fail to attain even this amount of skill) will solve a few puzzles at the end, but very barren of any intellectual result in the way of mental training:—an algebra in which the interpretation of negative results and the use of the negative sign as a sign of affection has been ignored, or so lightly dwelt on, that the notion of the signs + and − as appropriately expressing opposite senses along a line, has to be elaborately explained as almost a new idea in commencing trigonometry; and further, an algebra which, as Prof. Chrystal has observed in his address to the British Association, is useless as an instrument for application to co-ordinate geometry, so that the student has at this stage practically to study the subject again, and only then obtains something of a true notion of what algebra really is.

With the foregoing general considerations as a guide, I will now examine in some detail the correlation or affiliation of the several branches of elementary mathematics to which they seem to lead.

Mathematics naturally begins by treating magnitudes with reference to the single element of quantity. The answers to the simple questions, How many? How much? How much greater? How many times greater? lead up to the arithmetic of abstract and concrete number, and the doctrines of ratio and proportion, and the development of these with the use of the signs +, −, &c., as signs of the elementary operations, and letters to denote numbers or ratios, naturally leads to generalised arithmetic or arithmetical algebra. At this stage $a-b$, where b is greater than a, is an impossible quantity, and a negative quantity has by itself no meaning. In this earliest stage the magnitudes dealt with are either pure numbers or concrete one-dimensional magnitudes, value, time, length, weight, &c., whose measurements are assumed as known. There are few magnitudes which are metric or quantitative *only*, but all magnitudes have quantitative relations which may be regarded apart from their other relations, and so may be the matter or subject of arithmetic, if they are such that their quantity can be estimated definitely or measured. Purely metric magnitudes are such as can be conceived to be reduced in quantity down to zero or annihilated, but of which the negative is inconceivable, so that at zero the process must stop. Such are many magnitudes that are measured by integral numbers—as population, numbers of an army or a flock, a pile of shot, &c., or continuous magnitudes, such as mass, energy, quantity of heat or light, the moisture of the atmosphere, the saltness of water, &c. But there is a far larger class of magni-

* The allusion is to a paper which used to be set at the annual May Examinations at St. John's College, Cambridge, consisting of seven very hard equations and equation problems, familiarly known as the "seven devils." As a test of a certain kind of skill in algebraical operation and of ingenuity and clear-headedness it was not without considerable value, but it tended to produce false notions of algebra in its relations to mathematics generally.

tudes, of which it is true that not only the opposite or negative can be conceived, but that they cannot be fully treated without regard to such opposite. For these, reduction to zero, or annihilation, is only a stage in passing from the magnitude to its opposite, *e. g.* time after and time before a given epoch, lengths forward and backward along a line, receipts and payments, gain and loss, and so forth. The consideration of such magnitudes at once leads to the scalar subdivision of the one-dimensional stage. In this, magnitudes which are themselves purely scalar, or the scalar elements of more complex magnitudes, are alone considered. But to the quantitative element is now superadded the notion of sign or sense, appropriately denoted by the signs + and −, which, without ceasing to be signs of operation, are now regarded also as signs of affection. The introduction of this notion leads at once to scalar algebra, in which $a-b$, where b is greater than a, is no longer an impossible quantity, and a negative result has a definite meaning, so long as the magnitudes dealt with are not purely metric. The step from arithmetical to scalar algebra, though very simple and almost insensibly made, should, I think, be much more distinctly emphasized in our teaching and our text-books than is usually the case. Exercises in metric and scalar readings of the same simple expressions should be frequent, and negative results, whenever they occur, examined and shown to be impossible only if the magnitude in the question is purely metric, but interpretable if it is scalar. Thus the idea would be gradually evolved that the impossibles or imaginaries of algebra are so in a purely relative sense and with regard to the particular subject-matter treated of, and it would become readily conceivable that the remaining impossible quantity $a + b\sqrt{-1}$, to which form scalar algebra, working on the basis of its laws of combination, would show that all expressions may be reduced, may be completely interpretable when ultra-scalar magnitudes form the subject of investigation.

Passing now to the consideration of special magnitudes and how far their discussion can be carried in the one-dimensional stage, I think we shall arrive at some important practical results.

The scalar element of space is length measured forwards or backwards along a line, and the resulting geometry is the simple geometry of points on the same line. Starting from the definition that— AB is BA, the fundamental proposition is that AB + BC = AC, whatever be the positions of A, B, C on the line, and this with a few simple consequences completes all that is necessary to be considered in linear geometry.

Combine with this the notion of time, and the science of linear or scalar kinematics emerges. This includes the measurement of the motion of a point along a given line by the scalar magnitudes, *speed** and *acceleration*, and the discussion of different kinds of linear motion, uniform and uniformly accelerated, and so the laws of falling bodies. When the notion of a variable rate became firmly grasped, the investigation might be extended to some simple cases of variable acceleration without any large demand on algebraical skill, and so the fundamental notions of the fluxional or differential calculus and some idea of its scope and aim be attained.

Introduce now the notions of force and mass and the axioms of force or motion as contained in Newton's laws, and the science of linear or scalar dynamics results. If we drop for an instant the notion of time, or rather of *change in time*, we have linear statics, which consists of little more than the single proposition—the "tug-of-war" proposition—that the resultant of any number of forces along the same line is their scalar sum. Linear kinetics, however, covers a wide field—the relations of force, mass and acceleration, their measures and their applications to simple cases of linear motion; the time integral of force, momentum; the space integral, work; energy, kinetic and potential; the relations of force applied to resistance overcome in simple machines working steadily; impulsive actions in collisions and explosions; and other simple developments—would here be studied in their simplest forms apart from any greater mathematical difficulties than arithmetic and very rudimentary algebra, and yet

* The term *speed* has been happily appropriated for the scalar element of velocity. A corresponding term is wanted for the scalar element of acceleration; no better word than *quickening* suggests itself to me.

involving almost every truly dynamical principle needed for the highest problems in dynamics. Here, with perhaps a few applications to other branches of physics, the range of the one-dimensional stage ends.

Proceeding next to two-dimensional magnitude, we commence of course with elementary plane geometry, in which the propositions, which are not purely descriptive, deal with the magnitudes considered in purely metric relations.

The introduction of the notion of sense for lines and angles, denoted by the signs + and—, leads in one direction to elementary trigonometry, and in another to co-ordinate geometry.

Kinematics is now extended to motion in two dimensions, and this should lead at once to the notion of velocity, accelertion, &c., as vector magnitudes, and with this the general notion of a vector and vector addition. In dynamics force emerges as a vector, and the composition of forces regarded as the addition of vectors lays the foundation of statics, or the relations of forces independent of the element of time, to be developed on the one side with the aid of pure geometry and graphical methods, on the other by the application of trigonometry. This is naturally succeeded by uniplanar kinetics, developed more or less fully till it extends to regions beyond the range of elementary mathematics. Algebra will have been carried on *pari passu* to meet the requirements of the special subjects, but will still remain scalar with its impossible of uninterpreted symbols.

The next step is to complete the algebra of vectors in one plane. The notion of a vector and vector addition will already have been grasped and will need only some further application and development, but the extension of the notion of multiplication to vectors in one plane at once leads to the already familiar algebra, but with wider meaning and without impossible quantities or uninterpretable symbols. The immediate result is a complete trigonometry, of which De Moivre's theorem, now completely intelligible and not a mere formula, forms the basis, and the higher developments of ordinary elementary algebra. It will then appear that ordinary algebra receives its full explanation in vectors limited to one plane, and it will naturally be anticipated that the algebra of vectors in any directions in three-dimensional space will be different from the ordinary algebra, an expectation which will be amply justified by the study of the algebra or calculus of quaternions, the grand discovery of Sir W. R. Hamilton, but to pass on to this would be to pass beyond the limits of what is, in the sense of our Association, elementary mathematics.

If the correlation of the elementary branches of mathematics, which I have now sketched out, is accepted as based on true principles, I cannot doubt but that it will lead to important practical consequences, the development of which I may safely leave in the hands of those who so accept it. There are, however, a few immediate deductions from it, which occur to me as naturally calling for expression before I close this paper.

In the first place I would observe that while I believe the several stages in the foregoing scheme to be natural and such as every teacher would do well to have in his own mind in arranging the course of instruction for his pupils, I do not at all regard it as marking out the exact order to be followed by each individual student. There is room here, still in subordination to the general scheme, for wide variation according to the different requirements of different students. It would in almost all cases, I think, be very unwise that any one of the stages should be completed before the next was commenced. For instance, though the theory of ratio is purely one-dimensional and metric, no one, I suppose, would think of dealing with it otherwise than in the incomplete form sufficient for arithmetic before commencing the study of the simple two-dimensional geometry of Euclid or our own text-book. And, again, how far scalar or linear kinematics and dynamics should be studied (or whether at all) before proceeding further in the two-dimensional stage to trigonometry, &c., is a question which may fairly be answered in different ways according to the different objects aimed at in the study of mathematics by different classes of students.

It appears to me, too, to follow from our scheme that, whatever may be true for the select few who aim at becoming mathematicians, for the great mass of

those with whom the great object is, or ought to be, intellectual training, algebra should be studied at first, not as a subject for its own sake, but as an instrument for use in other subjects. I hold that, unless pursued into its higher developments, algebra *per se* is not a valuable instrument of mental training. Can it be said that such algebra as is required (say) at the Previous Examination at Cambridge, a large part of which has had no application for the student in any other subject, is of any value at all proportional to the time it has taken him to acquire it? I think, then, that algebra should be studied piecemeal: first just that small quantity which is necessary for one-dimensional magnitudes treated as scalars; then, when the need was felt from the occurrence of problems requiring more knowledge of algebra, adding more, and so on continually, keeping up the study of algebra concurrently with, and only slightly in advance of, the requirements of the subjects to which it is applied.

Again, our scheme suggests, I think, a definite answer to the question:—What minimum of mathematics is it reasonable to expect every educated man, not professing to be a mathematician, to have acquired?

I think there are few who are satisfied with the answer practically given to this question by our Universities in their first examinations for matriculation or degrees. At Cambridge, the question with reference to the "Little Go" Examination is even now under consideration. I would submit that the subjects included within our one-dimensional scalar stage, together with elementary geometry and statics, treated geometrically, or by graphical methods only, from the two-dimensional, would constitute a far more satisfactory minimum than the present. This would exclude a good deal of the algebra now expected and the trigonometry, but would add linear kinematics and kinetics. The student, who had gone through such a course, would not probably be able to effect any but the simpler algebraical reductions or solve any but the simplest kinds of equations; but he would have gained some notion of what an algebraical formula means as the expression of a law, and be able to deduce from it numerical consequences and to follow out the simpler general results obtainable from it, and he would have acquired a clearer conception and higher appreciation than is common with people otherwise well educated of the part which mathematics plays in its application to the physicial sciences, and with it that sound dynamical basis which is the essential condition of a fruitful study of physics. I feel sure, too, that the consciousness of the student that he was dealing with actual living laws and not with the dry bones of algebraical processes or trigonometrical formulæ leading to no results, and that his mathematical studies were meant to be, and were, more than a mere mental gymnastic, would add life and interest to those studies which would react on the whole of his mental training.

I may note, further, that our scheme seems to give the best answer to the question which has frequently been mooted of late, in our Association as well as elsewhere, whether statics should precede kinetics, or whether it should be treated as a particular case of the more general science. Linear kinematics and kinetics, being one-dimensional and scalar, may well precede the study of statics, which deals with vectors, though not of necessity in the case of one who has attained sufficient knowledge of elementary geometry not to be stopped by mere geometrical difficulties, but vector or uniplanar kinetics, on account of its much greater complexity and its consequent larger demands on mathematical attainments, would in general naturally follow a somewhat detailed study of statics.

I will take this opportunity of making one other remark, which, if it does not directly arise out of the present discussion, is closely akin to it, and that is on the importance of our teaching of the several branches of mathematics being *proleptic*, or looking forward in one stage to what will be required in a higher stage. In definitions, for instance, of two that are equally good for the immediate purpose, that one is to be preferred which will be intelligible and useful when the term defined comes to be extended to higher matter.

Thus I conceive that multiplication should be defined from the outset in such a manner as would make it applicable to

a fractional as well as to an integral multiplier. If I explain that to multiply 6 by 5 is to repeat 6 five times and find the aggregate result, my explanation fails when I am asked to multiply 6 by $\frac{3}{4}$; but if I use De Morgan's definition that "multiplication consists in doing with the multiplicand what is done with the unit to form the multiplier," or an explanation of multiplication cast in this form, I have given an explanation equally simple with the former and applicable also to a fractional multiplier.

Again, in the very beginning of arithmetic, which is counting, I maintain that much would be gained if from the first the child were taught to count, not one, two, &c., but *nought*, *nothing*, or *zero*, one, two, three, &c.; and then if, later on, ordinal reckoning were made to accord with this, though here unfortunately language and usage fail to supply the word wanted, for which, for want of a better, I must coin the form *zeroth* (*noughtth* or *nothingth* being out of the question), thus: *zeroth*, first, second, &c. Then the transition to counting below zero by negative numbers would follow at once as by a natural development, when the need for it arose. Thus when it came to the notation of numbers, the place of a digit would properly be reckoned from the units as the *zeroth* place (not the *first*), and would be extended naturally by negative ordinal reckoning downwards, when decimal fractions are introduced.

This leads me to another illustration, which I am also anxious to introduce as a suggestion on its own merits. Prof. Chrystal has complained that to many students even when beginning coordinate geometry the idea of the *order* of a term or an expression is unfamiliar. Now it has occurred to me that this is just the word wanted, to replace the five-syllable word "characteristic," which has been used (or perhaps has *not* been used just because it is pentasyllabic) to express the distance of any digit of a number in order from the unit's digit. Let us speak of the unit's digit as of the order 0; the tens, hundreds, &c., digits of the orders 1, 2, &c.; and the tenths, hundredths, &c., of the orders -1, -2, &c.; and add to this that a number is said to be of the same *order* as that of its highest significant digit, and we have a language not only of the utmost use and importance in decimal arithmetic, but also at once applicable by the most natural extension to an algebraical expression arranged according to the powers of some letter or letters, while it would enable us conveniently to express in language numbers which transcend our ordinary numerical vocabulary, so that, for instance, 51×10^{12} might be read as 51 of the 12th order, and 53×10^{-12} as 53 of the -12th order, and so on.

In conclusion I will only add that, if in this paper I have in any parts expressed myself somewhat dogmatically, I have done so in the hope of challenging discussion, and only claim the acceptance of the views which I have tried to express *distinctly*, if *briefly*, in the event of discussion resulting in a verdict in their favor.

CONCRETE.*

By JOHN SLATER, B.A., F.R.I.B.A.

From "The Building News."

I have to-night to ask your attention to the means to be adopted for rendering buildings stable, and securing good foundations. This question of foundation is, perhaps, the most essential of any with which persons connected with buildings have to deal, for if the foundation be faulty, the superstructure, even if it should stand, will certainly suffer. It will be totally useless for the architect to design, or for the deft fingers of the mason to elaborate, the most delicate window-tracery, the most graceful piers and columns, the most stately towers and domes; or for the artist to enrich these creations with the most brilliant

* A lecture delivered at Carpenters' Hall on Wednesday night, March 17.

efforts of his genius, unless the edifice be founded so that no cracks or settlements occur to deface the decorations. In some localities, as for instance, where rock crops up close to the surface, a natural foundation is obtainable, which cannot be improved upon; but in the majority of cases, and especially in London and its neighborhood, it is almost impossible to find a good natural foundation without digging to a depth that is practically out of the question, on the ground of expense. Hence it is necessary to form artificial foundations, and the material principally used for these is concrete. Although the use of concrete as a building material is of comparatively recent date in this country, it was known and extensively used by many of the nations of antiquity. There is ground for thinking that the Greeks were not unacquainted with its use, especially in the Italian colonies of Magna Græcia; and as far distant as Mexico, in many of those curious pyramidal buildings which are the remains of an unknown civilization, concrete foundations have been discovered. But when we come to those grand old builders, the Romans, who were, *par excellence*, the scientific constructors and engineers of ancient times, we find that they used concrete to an extent with which nothing that has as yet been done in modern times can compare. One reason for this was that the Romans found ready to their hand the best materials that exist in the whole world for making good concrete—viz., the travertine limestone, the pozzolana, which is a fine sandy earth of volcanic origin, and a beautiful clean, sharp sand. The use of concrete by the Romans dates back as far as the time of the Kings—*i.e.*, anterior to 509, B. C.; and no less than five kinds of concrete walls are described by Prof. Middleton, who has recently devoted a great deal of careful attention to the methods of construction of the Romans. In addition to using concrete for foundations, they used it without any facing for walls, which were constructed very nearly as described in Mr. Tall's or Mr. Drake's patents, which were taken out a few years ago. Wooden posts were fixed in the ground about 3ft. apart, and boards were nailed horizontally to the posts, and then the intermediate space was filled in with concrete in a semi-fluid state, and as soon as this had set, the boards were moved one stage higher. Thus the concrete formed one perfectly solid mass, and some of these early Roman walls are so solid and hard still that quite recently it has been found necessary to destroy them with dynamite in the course of improvements that have been made. Even when the Roman walls appear to be of brick or marble, this is in every case a mere facing or veneer, and the core of the wall is of concrete. They also largely used this material in constructing very extensive vaults, for supporting upper floors, staircases, ranges of seats, &c. Concrete also formed the basis of all Roman roads; in the early examples the blocks of stone laid on the concrete were much more closely jointed than was the case afterwards. There can be no doubt that the lasting nature of the Roman concrete was due, in addition to the excellent materials, to the careful way in which it was made, and I shall have to refer again to the method of making concrete adopted by the Romans. The French have been very great users of concrete, or *béton*, as it is there called, since the year 1820, and the material has been used in enormous blocks in docks at Toulon, Marseilles, and other places, and in the construction of the Mole at Algiers, and the breakwater at Cherbourg. In this country concrete was employed in very early times, as, for instance, in the foundations of Westminster Abbey, and in the older portions of the sub-structure of St. Paul's; but its use died out, and for a long while the only method adopted for making stable artificial foundations in bad soils was pile-driving. Although Mr. Semple, of Dublin, in 1776, suggested the use of a mixture of sand, gravel and quicklime for structural purposes, it was not till the beginning of this century that concrete was recognized as a building material. Colonel Pasley says that the first use of concrete for foundations was by Mr. Smirke at the Millbank Penitentiary in 1817, and there is a story that the discovery, or rather re-discovery of the fact that lime would combine with gravel and form a sort of artificial stone was a pure accident, owing to the upsetting of a barge-load of lime during the erection of Waterloo Bridge, when it was found

that the loose gravelly bed of the river had been rendered hard and compact by the action of the lime. Now, what is concrete? It may be defined as an artificial stone composed of a mixture of hard materials, such as ballast, flints, stone chippings, broken bricks, pottery, or iron slag, called the "aggregate," and a cementitious material called the "matrix," thoroughly combined, together with a sufficient quantity of water. The value of the concrete depends almost entirely upon the quality of the cementitious material, whether lime or cement, and it is most important that you should clearly understand the difference in the properties of various kinds of lime. I must make a short digression here in order to describe them. You are, of course, all aware that lime is produced by burning limestones, and upon the constituents of the limestone depends the quality of the lime. First, there are the rich limes produced from stones which are perfectly pure carbonate of lime—such as the upper and middle chalk formations and white statuary marble. Lime made from these stones is commonly called chalk-lime, and is much used for mortar and concrete in country districts where chalk is plentiful. This lime, when mixed with water, commences to slake, as it is called—*i.e.*, it swells, hisses, give off hot vapor, and falls into powder; and if it be then mixed with water, it will always remain of the same consistency, and never harden at all; and as it is soluble in fresh water, mortar made of chalk lime should never be used for external work, as the action of the weather will soon render the joints quite soft, and anyone who has been present during the pulling down of buildings, the mortar of which was composed of chalk lime, will have noticed how easily the bricks are separated, and what a large amount of dust comes from the demolition. Then come the poor limes, made from the argillaceous or clayey limestones, which contain, in addition to the carbonate of lime, various foreign substances, chiefly silica and alumina, and often a small quantity of oxide of iron. The existence of a small quantity of these foreign substances—as in the Dorking, Halling, and Merstham limestones—causes the lime made from them to show much less violent action when slaked, and enables it to set after slaking, but not under water. Next come the blue lias limestones, which contain a greater quantity of silica and alumina, and produce what is called hydraulic limes, which will set and continue to harden under water; and after these come the so-called natural cement stones found in the London clay formations at Harwich, Sheppey and the Isle of Wight, or in parts of Yorkshire, in the clays of the oolitic series. These contain even more silica and alumina, and from them used to be manufactured the Medina and Roman cements which had the power of hardening under water very quickly. These cements enjoyed a high reputation for many years, but they are now almost entirely superseded by the artificial cements of which Portland is the type. You may take it roughly that rich limes contain over 90 per cent. of carbonate of lime; greystone limes, such as Dorking, about 80 per cent.; blue lias from 66 to 70 per cent., and cements 40 to 50 per cent. When it was a well-ascertained fact that for building purposes lime obtained from the limestones containing a considerable proportion of argillaceous earth was the best, the idea began to gain ground that an artificial cement could be manufactured by mixing chalk with various kinds of clay and calcining the mixture. The patent granted for the manufacture of an artificial cement of this kind, called Portland cement, from its resemblance when set to Portland stone, was taken out by a Mr. Aspden in 1824, who describes himself as of Leeds, in the county of York, bricklayer; but the manufacture was not placed on a really scientific basis till Colonel Pasley carried out his elaborate series of experiments during the years 1826 to 1836. As so often happens with scientific discoveries, it appears to have been by pure accident that he discovered, after many failures, the superlatively good qualities of the alluvial clay or mud of the lower basins of the Thames and the Medway. This clay, which has been deposited in the tidal waters of these rivers, contains exactly the right proportions of silica and alumina for combining with the chalk. It would take too long to describe in detail the manufacture of Port-

land cement; but, briefly, it is this: the chalk and clay in the proportion, as a a rule, of about 70 per cent. of the former to 30 per cent. of the latter (though these proportions vary with the nature of the chalk), are ground under rollers and intimately mixed together with a great quantity of water until the mixture is of the consistency of thin paste, which is allowed to settle, the water is drawn off, and the residue is left to dry. This is then cut out in lumps and taken to the kilns, where it is burnt at a high temperature, and it is very important that the whole of the mixture should be thoroughly burnt. The effect of the burning is to drive off all the carbonic-acid gas, and to leave the mixture in the form of clinkers. These are then carefully ground to a powder under millstones, to such a degree of fineness that it will all pass through the meshes of a sieve having 625 holes to a square inch. The weight of the ground cement should be as nearly as possible 1 cwt. per striked bushel, and the specific gravity 3.00. The essential difference between lime and cement is that lime slakes with the addition of water, while cement does not; lime powder, after slaking, will not set if mixed up with water, unless sand be added to it, while cement will set at once, and equally well in the water and the air. The property of setting quickly, and setting under water, makes Portland cement of the greatest value, and its use for concrete is extending every day. Now, with regard to the aggregate, this may consist of ballast, stone chippings, broken bricks, &c., but the latter should never form the whole substance of the aggregate, and care should be taken that the pieces are not too large. In the case of ballast, it is most important that it should be clean and free from any admixture of loam or earthy substances. And there is one other point to be remembered, which is, that the concrete will be much stronger for the admixture of a small quantity of sharp sand, which will fill up the interstices between the pebbles, &c., and will make a much more solid mass of the whole. Having thus described the materials of which concrete is composed, I now come to the mixing process, and this is a matter which is far too often neglected. We all know the good old rule-of-thumb way in which ordinary builders' laborers mix up the concrete: a heap of ballast and broken bricks is piled up, a certain, or rather very uncertain, quantity of lime is poured out on it from a sack; then water is added according to the discretion of the mixer, and the mass is quickly turned over and wheeled or shot into the trench; and a very superficial examination is often sufficient to show numerous nodules of unslaked lime after it has been thrown in. Now, this is a most unscientific and improper way of preparing concrete; the great essential is that the lime should all be perfectly slaked during the mixing of the concrete before it is thrown into the trench, and that exact proportions should be maintained. For ordinary foundation purposes, if what is called stone lime be used, two measures should be prepared, the cubical contents of the one being four times that of the other. The large measure should be filled with ordinary ballast, and turned out on a boarded platform; to this should be added a small measure full of sand, and then a small measure full of lime; this will give the proportion of five parts ballast and sand and one of lime, and if this be well mixed and turned over after the water is added, which should be done gradually and in small quantities, it will make a very good concrete for ordinary purposes. If the ballast and sand before the admixture of the lime amount to a cubic yard, it will be found that about 30 gallons of water will be required to mix it thoroughly. This mixture should be then wheeled and thrown into the trenches, *not* from a great height, as used to be considered essential, for, if so, the heavier particles tend to fall to the bottom first, and the mixture will not be so well amalgamated, levelled and rammed. The French method of making concrete, or *béton*, which is almost exactly the same as that adopted by the old Romans, is undoubtedly superior to ours. They invariably mix up the lime and sand to form good mortar *first*, and then mix in the pebbles with it. A heap of good stiff mortar is first prepared, with a moderately hydraulic lime and sharp sand; a barrowfull of pebbles, which have been washed, are then spread out on a platform; over it is spread a barrowfull of mortar;

then a second barrowfull of stones, and and then another of mortar, and the whole is turned over with spades, and dragged backwards and forwards with rakes till the pebbles have become thoroughly enveloped in the mortar, and the whole mass is then thrown into the trenches. An extra precaution against deterioration of the concrete by contact with loamy earth is adopted in the best work by covering the bottom of the trench with a thin layer of sharp sand. The washing of the ballast is an excellent thing, as it tends to clear it from any earthy particles that may have become mixed with it. There can be no doubt that this is a far more scientific method of making concrete than the former. If the mortar is well made you get the pebbles more thoroughly amalgamated, and you insure that the lime shall be thoroughly slaked before the concrete is spread; but it is also more expensive, and I should not consider it necessary to use this method in ordinary cases. But where the soil is very wet, or in any case where the stability of the foundations is of very great importance, I should always recommend the use of cement concrete. With ordinary care in mixing this, supposing the materials are of good quality, you know you can rely upon its setting quickly, and forming a perfectly solid foundation, and you need be under no apprehension of having it spoilt by the inroad of water. The cost is more than that of lime concrete; but not so much more as the difference in cost of lime and cement, because you can use less cement proportionally. Six parts, of ballast, one of sand, and one of Portland cement will make a concrete good enough for almost anything in the way of foundations. Care should be taken that not too much water is used. Faraday, the eminent chemist, said that in the production of concrete the great thing was the discreet and accurate use of water. If too much be used, it will wash the cement away from the particles of the mass before it has time to become thorougly indurated. If the trench in which the concrete is to be spread is not too deep—that is, not above 18 in.—my own opinion is that you will get a harder and more solid mass by filling it up at once to the full thickness, and not putting the concrete in in layers; but if you have to put the concrete 5ft. thick, it must, of course, go in layers. In any case, it will be much improved by being well rammed after levelling. In such a material as concrete there must be a number of minute air spaces. You can see them with the naked eye in concrete that has set, and the act of ramming will drive out much of the interstitial air, and make the particles of the mixture more compact; and the denser such a material is, the stronger it is. Numerous experiments have been made to ascertain the loss of bulk in making concrete. Professor Hayter Lewis found that 27 cubic feet of Thames ballast, mixed with 4½ cubic feet of lime, and 40 gal. of water, made exactly one cubic yard of concrete, and, in some tests made by the Royal Engineers, it was found that 27 cubic feet of broken stones, 9 cubic feet of sand, 4½ cubic feet of Portland cement, and 25 gal. of water, exactly made a cubic yard. The difference between the two experiments may be accounted for entirely by the presence of the sand in the latter case, because the probability is that if a measure containing a cubic yard were filled with broken stones or ballast, it would still hold 8 or 9 cubic feet of fine, sharp sand because the pebbles would not lie close. It is sometimes stated that concrete expands after being mixed. If it does, it is because it has been improperly mixed, and any expansion that takes place after mixing can only cause some disintegration to take place. Hitherto I have spoken of concrete as used for foundations only; but there are many other purposes for which the material can be employed. I suppose it is not much more than twenty years ago that, building materials and labor being at a very high price, and by no means of very high quality, the idea began to gain ground that concrete might be used for the walls of buildings. I have already alluded to the fact that the Romans used it for these purposes, and that, too, although they only had lime, whereas we have Portland cement. But the mixing of the pozzolana, which I have previously mentioned, with the lime gave it many of the characteristics of a cement. The Italian architect, Palladio, writing 300 years ago, gives a very good account of the Roman method of wall

construction. He says: "The ancients used to make walls called 'reimpiuta'—*i.e.*, filled up with ragged stones—which is also called coffer-work, taking planks and planting them edgewise in two rows, distant from one another the thickness of the walls, and filling the space between them with cement, stones of all sorts, earth and mortar mingled together, and so on from course to course." This method of using concrete for walls is called monolithic, the concrete being simply poured in a semi-fluid state into the position required, to which it is confined by boards, and it sets in that position, so that the whole of the wall is one compact homogeneous mass. Another method is to form slabs of concrete by casting it in moulds, and allowing it to set there, and the slabs are then taken out of the moulds and carried to the place required, and used in the ordinary way, just like bricks or stone. The former system, if only ordinary care be taken, makes undoubtedly the strongest work, as there are no joints, either vertical or horizontal, and, moreover, no skilled labor is required in this construction, ordinary laborers being able to mix the ingredients and fill in as required. Several systems of apparatus have been invented for confining the concrete to the requisite thickness of wall and for shifting the moulding boards from one stage to another, and many of these are of a somewhat complicated character; but it is very doubtful if any material advantage is gained over the simple plan of nailing the boards to upright posts and filling in between. Walls thus constructed are really stronger than brickwork, drier, and more cheaply built; but great care must be taken in the preparation of the concrete: the cement must be of the best; the aggregate must be broken to the proper size, and the whole thoroughly well mixed. If these precautions are taken, the thickness of the walls may be about 20 per cent. less than with brick. The Metropolitan Board of Works, after a long deliberation, have at length announced their intention of sanctioning the use of concrete as a building material for walls in London, and place the following restrictions on its use—viz, that the proportions shall be one part of cement, two of sand, and three of coarse materials, which may be ballast, gravel, broken bricks or stone, or furnace clinkers; but the coarser materials are to be broken small enough to go through a 2 in. ring. The walls are to be of the same thickness as brick walls, and to be carried up between parallel frames, and the district surveyors are to see that the regulations are properly carried out. I think these regulations too strict as to the thickness of the walls, and as to the proportion of cement, particularly as extensive ranges of buildings have been put up in Southwark where the cement was gauged eight to one. I rather pity the district surveyors in their work of supervision; but the Board seem to have missed the most important point of all—viz., the quality of the cement—and they certainly ought to give their officers power to test this, for, as I have pointed out, serious consequences will ensue if this be not of the best kind. The second, or block system, has, however, some advantages: no particular building apparatus is required; any imperfections in the concrete can be discovered before it is used; the blocks can be made of any required section and of any size, and permanent tints can be given to the blocks by mixing various mineral coloring matters with the aggregate in the moulds. But for laying these blocks, just as much skilled labor is required as is the case with bricks and stone, and, of course, mortar and cement must be used to bed the blocks in; in fact, this is merely artificial blocks of stone instead of natural ones; but this artificial stone is really concrete, and as such it possesses virtues which may be sought in vain in any of the natural building stones, and therefore no lecture on concrete would be complete without a reference to the artificial concrete blocks which are very extensively used at the present time. I believe the first artificial stone which was used in this country was Ransome's, which was patented in 1844 or 1845. This consisted of a mixture of sand, silicate of soda, powdered flints, and a little clay, which was worked up to the consistency of putty, pressed into moulds, dried and burnt, and this burning, in my judgment, takes the material out of the category of concrete stones. Some years later, however, Mr. Ransome found that by dipping the moulded mixture into a

bath of chloride of calcium the burning could be dispensed with, and a series of experiments made in 1861 by Professor Frankland showed most conclusively that Ransome's patent concrete stone when only a fortnight old was equal to the best of the natural stones. Soon after Mr. Ransome's first patent, in 1847, a Mr. Buckwell obtained a patent for "Granitic brescia stone," which, I believe, was used in 1851 in the Hyde Park Exhibition. This wase ssentially a concrete, as it consisted of fragments of suitable stone, broken into small pieces and mixed with cement, with a small quantity of water, not more than enough to bring it to a damp state. This was put into a mould and powerfully compressed with a percussive action, and more of the materials added, until the requisite thickness of block was obtained. The block was thus rendered very dense and compact, and this artificial stone was used for water-tanks, than which no severer test can be applied of the qualities of an artificial stone. At the present day the artificial stone which is most used is the well-known Victoria stone, the patent for which was originally obtained by a Mr. Highton. The aggregate of which this stone is composed is ground Leicestershire syenite, a species of granite containing horn-blende instead of mica, and lacking quartz, which is thoroughly washed, so that no earthy particles remain, and an ingenious machine has been patented for doing the washing business. After being washed, the aggregate is carefully mixed with a certain quantity of Portland cement of the very best quality, and is placed in iron-lined wooden moulds, which are filled to the top, but no pressure is applied; after the concrete is set it is taken from the moulds and placed in a bath of liquid silicate of soda, and after ten days' immersion, the block becomes so thoroughly impregnated with silica that nothing but the strongest acids will free it again. The stone thus becomes intensely hard, and quite impervious to weather action—in fact, its hardness increases with time. This property makes it invaluable for copings, sills, paving, &c., and it has another advantage over ordinary stone—that heads and sills can be cast in as long lengths as can be desired, thus avoiding joints. It is used also for sinks and other such purposes. The silica used in the manufacture of this stone is obtained from the Farnham stone found under the Surrey chalk beds, and is boiled in coppers with caustic soda. One of the most enterprising modern pioneers in concrete building was the late Mr. W. H. Lascelles, of Bunhill row, who was a most sanguine believer in the future of this material. Mr. Lascelles actually built cottages, which were not only habitable, but comfortable, the walls of which were only 1½ in. thick, formed of slabs of cement concrete, the outer side cast in imitation of brick or tiles, and the inner side left rough for plastering. These very thin walls appear to have kept out the weather perfectly, but moisture condensed on the inner face, so Mr. Lascelles improved upon his original idea by having a double casing of slabs with a cavity between. He also formed floors of concrete, window frames and roofs; but the latter did not turn out very successful, as there was always a certain amount of shrinkage. This system did away almost entirely with the use of wood, and consequently the houses so built were as near being fireproof as they could be got. Mr. Lascelles' concrete is composed of four parts of powdered coke and one part of cement mixed together in a mill, with a small quantity of water, and cast in moulds without pressure, and by mixing metallic oxides in the form of powder with the cement, the concrete is colored any desired tint. Very excellent specimens of mullioned windows, chimney caps, head and sills, strings, copings, panels, and over-mantels are made in this material, and are largely used as a substitute for stone, and it is much cheaper than stone; but I am bound to say I have seen cases where the color has not been retained as it ought to be, and I am informed that this is caused by the workmen giving the slabs a top dressing of colored cement after they come out of the moulds. Of course this should never be done, as the color should really penetrate some depth into the mass of concrete. For standing a London damp and smoky atmosphere there can be no doubt of the great superiority of this concrete to almost any natural stone. Messrs. Lascelles also make a very good wall on what is termed Pot-

ter's patent. In this, a casing of concrete slabs, of which one face is fair, is put up, and ordinary concrete filled in between just as in the way I described in the wooden framework; but as the slabs are intended to remain, they are formed with a key, so that when the core of concrete sets, it is quite impossible for the skin of slabs to move. Among the numerous purposes for which this material is used may be mentioned silos, water-tanks, sewer-pipes, columns, &c. It would occupy too much time were I to attempt a description of all the methods of concrete construction that have been invented, such as Tall's, Drake's and others; but the most recent of them—the system patented by Messrs. West—has various novel features about it which deserve attention. This, like Potter's system, is a slab construction filled in with rough concrete; but the form of the slabs is ingeniously arranged, so that no temporary tie or external support is required during building. The slab itself is made of concrete cast in a mould, so that on one side is a finished face, plain or ornamental, as the case may be, and on the other a sunk panel about half the thickness of the slab itself, with its edges undercut, so that when in position, and the mass of semi-liquid concrete is poured in, the slabs are securely keyed to the general mass. Dovetail mortise-holes are also formed in the top and bottom edges of the slabs, in order that when laid they may be kept in their proper place by simply pouring into these holes some quick-setting cement. There is also a narrow groove along the edges of the slab which, when filled with cement, acts as a joggle joint, keeping the slabs together. An inner and outer casing of slabs is thus set up, and the plastic concrete poured in, filling up the sunk panels and making with the slabs a perfectly solid wall. For openings, jams are moulded, having recesses, or dovetailed holes, into which the fluid concrete may penetrate, so that they can be thus keyed to the general mass of the wall. The slabs are made either rectangular or hexagonal on plan, and as they are all cast in a mould, there is, of course, not the slightest difficulty in arranging for circular work, splayed angles, or anything of that kind. There has always been considerable difficulty in arranging for moulded or enriched stringcourses or projections, with concrete, and this difficulty is proposed to be overcome by casting the moulding first and then applying it to the slabs while they are in a plastic state, the moulding thus becoming part of the slab, which is then fixed in the required position. The moulds for casting these slabs are made of metal and lined with indiarubber. Similar slabs can be moulded with curves for constructing domes, and ceiling slabs can be made with rebates, so that they can be supported on iron joists or girders. This system of concrete building is certainly the most scientific and the most complete that has yet been invented, and I have no doubt whatever that a building thus erected would be perfectly dry and very strong; but I am somewhat disposed to think that the system is a little too complicated to be cheap, as the labor required for properly setting the slabs in place and cementing them together would nearly equal that required for a stone wall. The inventors have, however, shown so much skill in maturing their design and providing for all difficulties, that it is quite possible they may soon be able to point to actual works carried out on their principle, and to give accurate details of cost, which I am not able to do now. A very ingenious traveling scaffold and concrete elevator have also been invented by Messrs. West, which obviate the necessity of erecting a scaffold all round the work, and require no putlog holes to be left; and undoubtedly some such arrangement as this has been a great desideratum as an auxiliary to concrete construction. There can be little doubt that this system of concrete building would be of most material use in the construction of farm buildings, cottages, &c., in country districts far removed from railways, as the slabs are light and portable, and the material for the filling can generally be obtained on the spot. For paving purposes, concrete is, of course, excellently adapted; but it is very difficult to get ordinary workmen to lay a concrete floor properly. What they like is to lay the concrete and let it get hard, and then finish off the top with a thin coating of neat cement. This looks very well when it is first done; but sooner or later the thin coating begins

to flake off or crack, and looks very bad. The proper way is to break up the materials of the concrete to a small size, and then, in laying it, to trowel it off at the top as smooth as possible, so that it is all one mass and no layers exist. Portland cement should always be used, and if ordinary care be taken, there is no reason why a laborer should not lay an excellent concrete floor. There are many patents for concrete paving, of which I may mention Drake's granitic concrete and Macleod's granitic, which has been largely used in the North of England for warehouses, stables, &c. It is not cast in blocks, but laid *in situ*, and it can be made to take somewhat of a polish if desired. This forms an extremely hard, impermeable pavement, and it looks very well; but I really believe the whole secret of the excellence of these patent systems of paving lies in the careful manipulation of the materials and the sparing use of water. I may state here that for engine-beds concrete is, in many respects, far superior to stone, as it is not liable to chip and crack, and it is very much less expensive. I now come to the last division of my subject, and that is the use of concrete for vaults, and in fireproof construction. Everyone is acquainted with the fact that an ordinary arch exerts a thrust which has to be counteracted, or it would soon push out its abutments. A concrete arch, however, after it has set, forms a complete homogeneous mass, and exerts only a dead weight on its supports. The Romans were aware of this, and constructed the boldest and most extensive vaults of concrete—as in the Baths of Caracalla, and the House of the Vestals lately excavated. They were careful, moreover, to make the concrete used for these purposes of lighter materials than that employed for walls or pavements. The great dome of the Pantheon was constructed entirely of concrete of varying thickness, and the walls supporting this enormous mass were 20 ft. thick. In the House of the Vestals the whole of one of the upper floors, about 20 ft. span, consisted entirely of a great slab of concrete 14 in. thick, merely supported by corbels projecting from the walls, and in the Baths of Caracalla there are still extensive remains of large concrete vaults. We, in this country, have not yet obtained satisfactory evidence of the safe span and thickness of a concrete vault; but the material is very largely used to form small arches in fireproof floors. It is quite impossible to treat the very important question of fireproof buildings fully at the fag end of a lecture—the subject demands a whole evening to itself; but whatever system of fireproofing be adopted, concrete will prove to be the most important element in it. Whereas, the opinion used to be held that iron girders and columns as supports to a building were sufficient to make it fireproof, we have been taught by sad and costly experience that this is very far indeed from being the case. In the United States and in France they are much more particular than we are in this matter, and, in the former country, it is laid down as an incontrovertible maxim "that no building can be fireproof unless all constructional ironwork be protected," and no better material can be found as a protection than concrete. Stone is utterly valueless in this respect, as it will crack when heated, and give way without any warning whatever. Fox and Barrett's system consists in filling in concrete between wrought-iron joints, the concrete being supported on fillets of wood placed about ½ in. apart, and resting on the bottom flanges of the iron joists, the underside of the wood fillets being plastered. Either the concrete is carried up the requisite height and forms the floor, or if a wooden floor is required, small joists are cut to a dovetail section and imbedded in the concrete, and the floor boards nailed to them. Dennett's system is almost exclusively a concrete construction, consisting of concrete arches supported next the walls on projecting courses, and by hollow iron joists at intermediate points. In this system gypsum is mixed with the Portland cement to form the matrix, as experiments have shown that this substance can be heated to whiteness and then suddenly cooled without being injuriously affected. In Hornblower's system the iron girders are surrounded by cement, and inclosed in a fireclay casing, supporting fireclay arches. Even concrete arches supported on triangular-shaped wooden joists form a floor which is very largely fireproof. If iron columns are used, a temporary wooden casing

should be erected round them, leaving a space of about 2 in., which should be entirely filled up with Portland cement concrete, and if a fine face be desired this can easily be obtained by cementing the concrete. Messrs. Lindsay have patented two systems which comprise the use of steel decking, as it is called, and concrete arches, the girders being entirely covered with concrete, both at top and bottom. The concrete used by this firm is very light; it is called pumice concrete, and is composed of washed coke breeze and sand mixed dry and Portland cement of the very best quality. It is, of course, self-evident that if you get sufficient adhesiveness and transverse strength, the lighter the mass of concrete is for upper floors or vaults, the better, as so much less weight is thrown upon the supporting walls or columns. The steel girders for this kind of floor are of peculiar shape, and the system is a novel one, and appears to me likely to prove of great value for buildings of considerable size, where girders are a necessity for supporting upper floors. These girders may be described as truncated, equilateral triangles, set alternately on their bases and their truncated vertices, and riveted together at their sides, forming a series of hollows and elevations. They are constructed of rolled steel about $\frac{1}{4}$ in. in thickness, and their depth need not be much more than half that required for an iron girder. When the weights required to be supported are not very heavy, a combination of these steel girders with ordinary rolled joists can be adopted. The iron joists can be placed about 14 ft. apart, and from the steel skewbacks riveted to the joists, arches of concrete can be turned on centring. There is a possibility with concrete floors that would withstand any ordinary strain, that the sudden fall of anything like a huge iron safe might break through the floor; and in order to avoid any risk of this kind, Mr. Lindsay runs steel wires through the joists the whole length of the floor before the concrete is filled in. These are about 18 in. apart, and are strong enough to hold up any exceptional weight that may by accident come upon the floor. In addition, these steel wires form a sort of nucleus around which the concrete sets. The total weight, girders and all, of these latter floors is considerably less than that of any other system, and they are extraordinarily strong. I have now endeavored to bring before you some of the purposes for which this common material concrete is adapted. Its use is extending daily, and in that extended use lies a danger which it behoves us all to guard against; whether you are employing it for floors, for pavings, for walls, for vaults, for architectural enrichments, or what not, it cannot be too strongly insisted upon, that scamping of every kind must be avoided, that the quality of the Portland cement used in its manufacture must be of the very best, and that no labor in manipulation must be spared, for if inferior materials be used, or carelessness in working, the results are sure to be disastrous, and grave discredit will be thrown upon a most useful building material. The subject is a sternly practical one, and it has been impossible to illustrate it by elaborate and beautiful drawings; but, at least, we can learn one lesson from it, and that is, the great, the incalculable value of thoroughness in all the work which we have to undertake. As I commenced by referring to the Roman builders, so I would conclude by pointing to them again as a model for us. Depend upon it, when they were building the walls of those edifices which are still the wonder of the world, they gave no thought to what posterity would think of them; they simply did their work in the best way they knew of, and spared no pains to make it good; and if we imitate them in this, we shall all, whether architect, builder or artisan, have the satisfaction of feeling that we have done some bit of good work; and although it is not given to us all to be great artists and to "witch the world" with noble buildings, we can at least put our whole heart into everything we undertake and display what has been described as the truest genius—an infinite capacity for taking pains.

THE Scotch railways are joining with those of England in the opposition to Mr. Mundella's Railway and Canal Traffic Bill. The principle it embodies of giving power to the Board of Trade to fix rates compulsorily is severely condemned by all in any way connected with railway interests.

THE CHEMICAL TREATMENT OF THE LONDON SEWAGE.

From "The Engineer."

The Metropolitan Board has boldly decided on treating the whole sewage of the metropolis by the chemical process which has been undergoing elaboration under its auspices during the last two years. In the resolution thus arrived at, the Board has the warrant of two reports, signed by Sir F. Abel, Dr. Odling, Dr. Alexander W. Williamson, and Dr. Dupré. These are high authorities; and, although it may be said that three of them were not originally disposed to admit that the Thames was in an offensive condition, yet there is the remarkable fact that one of the four—Dr. Williamson—was himself a member of the Royal Commission presided over by Lord Bramwell. Since that Commission took evidence, the chemical operations at Crossness have doubtless thrown further light on the subject, so as to justify some modification of the views previously entertained. The second, and final, report of the Royal Commission bears the date November 27th, 1884, whereas the first report from the four chemists is dated eleven months later. The interval was one of activity at Crossness, and the Metropolitan Board wished to know whether the process devised by Mr. Dibdin would work satisfactorily. Mr. Dibdin, the Board's chemist, was then using 3.7 grains of lime and 1 grain of protosulphate of iron per gallon of sewage. The chemical referees, if we may so term them, expressed their opinion that the result would be "a very great gain over the discharge of untreated sewage;" and they further declared that the process, apart from the precipitating action, did exert "a distinct purifying effect upon the liquid part of the sewage." On the other hand, they considered that the effluent retained a sufficiently unpleasant oder to prohibit its discharge into the river during warm weather at all states of the tide. Had the report ended here, the verdict would have been a little discouraging; but there was an important supplement. The referees saw reason to believe, from what they had witnessed in the way of experiment, that the addition of manganate of soda and sulphuric acid to the effluent would so far deodorise and purify it as to allow of its being afterwards discharged into the river "at all states of the tide." It was, at the same time, a question whether this supplementary treatment would be necessary in the winter months. In their second report the referees decided that the deodorising process would be unnecessary during a considerable part of the year. For the purpose of deodorising the effluent during warm weather they recommended crude commercial manganate of soda, ranging in quantity between 0·5 grain and 1·5 grain per gallon of effluent, with a proportion of sulphuric acid equal to about one-third of the crude manganate.

The report of the Works Committee of the Metropolitan Board in reference to this subject explains that the evidence given before the Royal Commission was of so conflicting a character, that it was felt nothing short of a prolonged series of experiments on a tolerably large scale, extending over some months, and including day and night, would afford the information necessary before working plans could be drawn up for the erection of plant for the treatment of the whole of the sewage. Thus the Board went seeking for new light, and if the report, which includes Dr. Williamson as a signatory, is to be allowed any weight, we must believe that the Board found the object of its search in the experiments conducted by Mr. Dibdin. But behind the precipitation and the deodorization there was the *bete noir* of the sludge. To purify the sewage was one thing, but to get rid of the sludge was another. Reckoning the daily volume of the sewage at about 150 millions of gallons, the resultant sludge is estimated at 3,000 tons. This, when pressed, is reckoned at 850 tons of cake. It is well that Mr. Dibdin is able to use a comparatively small quantity of chemicals. The lime which he introduces will add about 40 tons per diem to the actual sewage re-

sidium, which is considerably less than the bulk which most chemical processes would leave to be dealt with. Still, there is the sludge, and no small quantity either. If some enterprising individual would take the lot, with all its virtues, he might have it for nothing, even though the Board had previously borne the expense of pressing it. The stuff cannot be burnt, for the fumes of its combustion are found to be objectionable, even in the not very savory neighborhood just outside the metropolitan boundary. Digging it into land is not an easy matter. Giving it away to the farmers is not altogether hopeful, considering the depressed state of agriculture. It might be used to raise the level of the low-lying lands bordering on the Thames; but the Board contemplates the contingency of flinging it all into the German Ocean. What effect this would have, it may interest some of the experts to determine. The sludge may feed the fishes, it may create shoals, it may go ashore, or it may happily disappear altogether. Some experience on this point has been gained at New York and Boston, but the London sludge will be on a scale pre-eminently large. We have already dealt with the proposal of Mr. J. Orwell Phillips, who elaborated a plan whereby the Beckton screw colliers would be made available for carrying off the sludge in the form of compressed cakes to be thrown overboard at sea. The Board has since invited designs for ships specially constructed to carry away the sludge, and have received as many as twenty-three designs in response. In respect to other arrangements, the Works Committee state that the contract drawings for the enlargement of the Barking sewage reservoir, and arranging it for precipitation and purification works, are in a forward condition, so that the contracts may be let in the course of the coming summer. The works may be completed and brought into full operation in the summer of 1888. Until then reliance is placed on the deodorising works already provided, and which, it is believed, will prevent any nuisance at the Barking outfall. Throughout the approaching summer nine millions of gallons of sewage are to be precipitated daily at Crossness, the remainder being deodorised until the process of precipitation has been extended to the whole of the southern sewage. With regard to the sludge, so much of it as nobody will accept gratuitously is to be sent in lighters out to sea, both in the liquid and in the cake condition, in order to ascertain the cost and effect of this mode of getting rid of it.

The cost of all these operations is, of course, a serious matter. Yet there is encouragement even in that direction. The capital expenditure for dealing with the sewage at the present outfalls is reckoned at about £750,000. The annual cost, including interest on capital, depreciation of plant, wear and tear, and all other expenses, is estimated at £118,000 per annum. When we referred to the subject some time ago, the annual cost was a trifle below this amount, but the first cost, including £131,000 for barges to carry the sludge, was £1,140,000. The Royal Commissioners reckoned that the chemical treatment of the London sewage would cost £200,000 per annum; but in so doing they were aiming at a higher degree of purification than that which is considered necessary by the Metropolitan Board. At Barking and Crossness there is no need to fear any pollution of a drinking supply, and hence a different standard of purity is permissible than would be proper in a part of the stream situated above the intakes of the water companies. Associated with the treatment of the sewage at the outfalls is another operation, which as yet has attracted but little notice. Commencing in July last year, the Board has proceeded to apply manganate of soda and sulphuric acid to the sewage *in transitu*. At more than a dozen stations on the lines of the great intercepting sewers these purifying re-agents have been introduced, the effect being, not to occasion precipitation of the solids, but to deodorise the sewage and prevent the escape of noxious gases from the ventilators. A further advantage consists in the fact that the sewage will arrive at the outfalls in a deodorised condition—a circumstance which, the Works Committee remark, will materially assist in the production of an effluent of a far better character than would otherwise be attainable. The character of the occasional discharge from the storm overflows will also be improved. Anything

that can assist the difficult process of sewer ventilation is especially to be valued, and the plan thus commenced by the Metropolitan Board will strike most persons as a happy expedient, the sewage being dealt with before it has time to become putrescent. The principle may be capable of extension, and so long as there is no increase of deposition in the sewers, the deodorising process may simply be limited by the question of cost. If the District Board and Vestries will each, in their own respective localities, imitate the example of the parent Board, the result will be so much the better. Another incident in this history is the extraordinary cheapening in the price of manganate of soda, in consequence of the development in the manufacture of this article by Mr. Dibdin. Owing to the limited supply and great cost of the manganate, Mr. Dibdin undertook to manufacture the article on a large scale. This so far stimulated the action of the manufacturing chemists that they now come into the market with large quantities of manganate of soda; and whereas some time back the price was £40 per ton, and the supply altogether inadequate, the figure has fallen to £11 per ton, and the supply is practically unlimited. The real use of the manganate of soda, in conjunction with sulphuric acid, is the production of permanganic acid. It is represented by the Board that the purifying agency of this compound is such as to render filtration through land unnecessary. This may be called the turning-point of the whole controversy. It is urged in certain quarters that the Board should implicitly observe the recommendations of the Royal Commissioners. But the reply of the Board is that, by means of this cheap and extensive supply of manganate of soda, it is practicable to apply permanganic acid on a scale which provides an equivalent for land filtration. Probably it is to this consideration that we may mainly attribute the approval which Dr. Williamson now accords to the treatment of the sewage at the existing outfalls. According to the available light on the subject at the time when the Royal Commissioners drew up their final conclusions, they advised that if the sewage were chemically treated at Barking and Crossness it should only be as a temporary measure, unless the effluent were subjected to intermittent filtration through a sufficient area of land. If the same result can be produced by chemical means, and at a greatly reduced cost, there is fair ground for the argument that the Board should not be forced to comply with the mere letter of the law, while amply fulfilling its spirit.

It is impossible to look at the plans of the Metropolitan Board, admirable as these may be, without remembering that another project has been brought forward, based on ample details, and possessing many features of merit. Of course we are alluding to the Canvey Island scheme of Mr. Bailey Denton and Lieut.-Colonel Jones. In the last report of the Works Committee of the Metropolitan Board in reference to this subject, the Canvey Island plan is discussed in a manner which seems hardly fair. The report of the Committee states that one element in the plan thus brought forward was that the Board should deliver the whole of the London sewage over to the projectors, accompanied by an annual payment of £110,000. The report goes on to say, "The view taken by your Committee, and also by the Board itself, upon this part of the scheme was that it would not be consistent with the Board's duty to hand over the sewage to be dealt with by other persons in consideration of a very large annual payment, and that the Board could not rid itself of its responsibility in that matter." A reply on this basis was sent to the Home Secretary, through whose department the Canvey Island project was in the first instance forwarded to the Metropolitan Board. The report ought to go on to say that to meet this objection Messrs. Denton and Jones offered to transfer their interest in Canvey Island to the Metropolitan Board, so that the latter body might keep the sewage under its own control, and carry out the plan without further reference to the original promoters. No doubt the Committee's report is correct so far as it goes. The first proposals were rejected for the reason assigned. But why do we hear nothing of the amended offer? As the report stands, the reason given for rejecting the Canvey Island scheme is inconclusive, seeing that it merely refers to a past phase of

the question, and makes no allusion to the form which it now assumes, this latter phase being entirely free from the objection urged against the first. It may be very true that in its amended form the project is not such as the Board feels called upon to accept. But due respect to all parties, even to the Board itself, demands that the true reason should be specified. We apprehend that the final objection to the Canvey Island scheme is really its costliness. Here, however, we touch a debated point, Mr. Bailey Denton contending that the plans of the Metropolitan Board will prove more expensive than the project which he has brought forward. The Board has evidently a different view of the case, and if the question is pressed, perhaps we shall hear more on that point. The Works Committee put into their report a statement based on information derived from Sir Joseph Bazalgette, that if the outfalls were removed to Hole Haven, the capital cost would not be less than £3,725,000, while the annual expenditure, including the treatment of the sewage there by precipitation, would be £215,000. As this latter amount is nearly £100,000 more than the annual cost of the scheme which the Works Committee have recommended, and which the Board has adopted, it might be inferred that carrying the outfalls still further on, so as to reach Canvey Island, would exhibit a yet greater excess. A subsidiary topic is that which relates to the proposal of Mr. John Orwell Phillips to carry the sludge out to sea in the Beckton colliers, on their return voyage to the North. The *Times* has complained that no reference to this proposal is to be found in the report of the Works Committee. Had such reference been made, it is to be expected the Committee would have stated that Mr. Phillips' proposal proved to involve a much greater outlay than was anticipated. Here again is a question of estimates, and the Board will justify itself by saying that it has to guard the pockets of the ratepayers, and therefore has to do its work in the cheapest fashion it can devise. Relative cost thus comes under consideration, and if it should yet appear that the Beckton scheme is cheaper than any other for the removal of the sludge, we shall doubtless hear more about it, and we cannot say that we quite despair on that point. At all events, something must be done with the London sewage beyond what has yet been accomplished, and the Metropolitan Board is addressing itself to the task in a manner which shows that it has decided upon a plan which it will carry out without loss of time, unless prevented by some interference from without.

THE CONSERVATION OF ENERGY.*

By S. DIXON, Manchester.

From "Iron."

It is the common experience of all men, but especially of engineers who were constantly engaged in controlling the great forces of nature, that various bodies or disposition of matter, possessed the power of doing work in a greater or lesser degree. It was not his purpose to enter into an examination of the whole of the various forms of energy, but he would take two or three with which they as engineers came most frequently in contact, viz., mechanical energy, heat and electricity. They frequently met nowadays with a steam engine driving a dynamo for producing the electric light, and they had there a fine example of the transformation of energy, embracing three or four of the most prominent forms. They saw, in the first instance, heat conveyed to the engine by the steam and disappearing in large quantities. In the second place, they saw mechanical energy produced in the motion of the various parts of the engine, this being transmitted, it might be, by a strap to a dynamo, and there disappearing. In the third place, they had the production of the electric current, conveyed, it might be, by a wire to a lamp and there disappearing, and the fourth

* Abstract of paper read before the Manchester Association of Engineers, March 14, 1886.

step they had the production of light scattering its energy around by its brilliant piercing rays. They might here note that in all these various forms they never saw one coming into existence without the disappearance of another; they saw heat disappearing and mechanical energy appearing, which on disappearing reappeared in the form of electricity, only to disappear as electricity and reappear as light and heat. They saw, therefore, in this combination a complete cycle of operations commencing with heat and going through two or three transformations to reappear as light and heat. They saw these transformations taking place, but it was not at first sight obvious that it was the same energy which was being transmitted throughout, but if they applied instruments capable of measuring the amount of energy in each form, and making due allowance for the leakage taking place at each stage, they would find that it was precisely the same amount of energy which was passing through the various forms. The great law of the conservation of energy taught them that they could not create energy, and the principle of the dissipation of energy taught them that they could not destroy energy. Yet, during the great transformation which took place, a vast amount of energy became degraded as it were, and rendered useless for the purpose of doing work. When they saw how our various sources of energy were being rapidly used up, he thought they could not but admit that an enormous responsibility rested upon them as engineers not to squander the stores of energy which were practically in their keeping for future generations. He thought there was nothing which they, in this truly wonderful nineteenth century, would so much regret as that the judgment of posterity on this our age should be that we had been so extravagant and wasteful of the great stores of energy that we had fearfully crippled, if not entirely ruined, the prospects of all succeeding ages. Seeing the vast importance of economising our stores of energy, they might possibly ask what had he to suggest in a particular way for improving on the present system, and, in reply, he would say:—1st. Let our engineers fully master the great principles of science, so that they may never be found attempting to set aside some of the inexorable laws of nature. 2d. Let us have a more truly scientific spirit applied to all our work, which carefully measured and estimated everything and took nothing for granted, however plausibly it might be presented. Let them carefully estimate the cause, and honestly measure the effect, and face it openly, no matter how unfavorable the results might be to them. Let them not be content to say that an engine, a machine, or any device whatever, would do a certain amount of work, but that they would be at once able to say how it did it, and how long it took to do it. He would suggest that the absolute efficiency of every engine or machine should be distinctly specified and insisted upon by the purchaser, so that in the struggle now going on only those firms which were really capable of constructing economical and highly efficient engines have any opportunity of survival, and that the construction of antiquated and extravagantly wasteful engines which yet survived should soon become a thing of the past. He would in fact urge measures which should facilitate the rapid survival of the fittest. The cheapness of coal in this country had in some respects been very disadvantageous, having fostered extravagance; but on the Continent, where coal was much dearer, the construction of economical engines had, he did not hesitate to say, been carried to a greater perfection than in this country, for any new device which ensured the most fractional increase of efficiency was at once adopted. He had often noticed, when discussing the peculiarities of their respective engines with continental engineers, that they always prominently spoke of their absolute efficiency in a truly scientific sense, as requiring so many kilogrammes of steam per horse-power (the only true test), whereas he feared that with us it was too often the diameter of the piston and the length of the stroke which absorbed our attention. It was, however, not only in steam engines that a greater application of scientific methods was required; in machine tools the need of improvement existed perhaps even to a greater degree. The long-continued commercial depression and the greatly increasing foreign competition had recently led to

considerable searching of heart and examination of the weak members of their organization, and if it had no other, it would have one beneficial effect in compelling engineers to equip themselves in the most efficient manner for the fight. During the palmy days which had now gone for ever, the tendency of engineering firms had undoubtedly been to become fossilized. How many firms could they see to-day, of even large extent, where machines were at work which positively gave one a shudder to contemplate, and which ought long ago to have been put under the steam hammer. They saw some firms holding on to these antiquated tools with the greatest tenacity, whilst young firms were springing up (on the Continent, it might be), and leaving these parental firms heavily handicapped in the struggle. Let them take, for example, such a simple instance as a lathe, which was generally regarded by many firms as being pretty much the same thing all the world over; yet so great was the difference that, with the most modern tool, the same man would be producing 20 feet of 2½-inch shafting per hour, whilst with old ones, to which they still clung so tenaciously, he was scarcely able to produce 20 inches per hour. It was not sufficient now that a lathe should do a certain work, but that it should do it in the least possible time. In the great competitive struggle for the survival of the fittest, they might well draw a lesson from what they saw in the struggle for pre-eminence amongst nationalities. What was the position of the nations with their antiquated armor, and what was their chance in the fight? As engineers they might well ask themselves what chance had those firms with antiquated machinery, and what must naturally be their doom. He was quite sure that there were at the present time many firms with machinery corresponding in antiquity and want of adaptability to the requirments of to-day, which might be fitly compared with the muzzle-loading guns, if not even with the flint-lock age, in weapons of war.

STRENGTH OF WHITE PINE, BRICKS AND STONE.

By PROF. W. A. PIKE.

Journal of the Association of Engineering Societies.

The author gives the results of tests recently made in the testing laboratory of the University of Minnesota. Sticks of thoroughly seasoned white pine were tested for tensile strength. They were dressed to a uniform scantling 12 inches in length, with shoulders on ends to take the pull. In scantling they varied from ¾-inch square to 1⅜ inches by 2½ inches; average specific gravity, 0.66. The average ultimate tensile strength was 7,373 pounds per square inch. It was observed that the longitudinal shearing strength of the ends of the sticks, in resisting the pull, was less than has been generally given. The ends had a shearing-area of 45 square inches; but it was necessary to spike and clamp the ends in order to prevent splitting. Thirty-five tests were made of white pinewood for resistance to compression, in which the pieces varied from 1-inch cubes to pieces 3 inches square and 54 inches in length. Of those which broke by direct compression, the crushing resistance averaged 5,283 pounds per square inch. One-inch cubes bore 7,800 pounds. Pieces 3 inches square and 54 inches long bore 5,222 pounds per square inch; 24 inches long, 5,038 pounds; and 12 inches long, 5,505 pounds per square inch. Of those which failed by a combination of crushing and bending, from 54 inches to 24 inches long, and from 4 by 2 inches to 2 to 1 inch in return, the average actual stress or load was about 3,000 pounds. The author argues from the results that the value of the usual constant in the ordinary formula for the resistance of struts is much too great.

Half bricks, placed between pieces of paste-board, were tested for crushing resistance. St. Louis bricks failed flat-wise under 6,417 pounds per square inch; edge-wise, under 4.080 pounds. Hastings red brick, hard, medium and soft, failed respectively under 2,017 pounds, 2,012 pounds, and 1,748 pounds per square inch.

RANKINE'S THERMODYNAMICS.

By DE VOLSON WOOD, C.E., M.A.

Contributed to Van Nostrand's Engineering Magazine.

II.

The expression

$$d\mathrm{Q}\frac{d(d\mathrm{U})}{dq}=d\tau\frac{dp}{d\tau}dv=d(d\mathrm{U}) \qquad (p)$$

is evidently true for imperfect as well as perfect gases when an actual pressure works over the space dv, for it is simply equivalent to $dpdv$. The next step is a novel one from a mathematical standpoint, for it is equivalent to

$$\frac{d(d\mathrm{U})}{d\mathrm{Q}}\int_0^{\mathrm{Q}}d\mathrm{Q}=\mathrm{Q}\frac{d(d\mathrm{U})}{d\mathrm{Q}}=d\mathrm{W},$$

or to

$$\frac{d(d\mathrm{U})}{d\tau}\int_0^{\tau}d\tau=\tau\frac{d(d\mathrm{U})}{d\tau}=d\mathrm{W}, \qquad (q)$$

which operation is equivalent to considering $\frac{d(d\mathrm{U})}{d\tau}$ as independent of τ, or, more generally, as constant during this integration. Here $d\mathrm{W}$ is an element of the total work, both external and internal. Now, $\frac{d(d\mathrm{U})}{d\tau}$ is not independent of τ, except for perfect gases. For perfect gases have, equation (a)

$$pv=\mathrm{R}\tau$$

hence for v constant we have

$$\frac{dp}{d\tau}=\frac{\mathrm{R}}{v}$$

which is independent of τ, and substituted in equation (p) gives

$$\int d\tau\frac{\mathrm{R}}{v}dv=\int\frac{\mathrm{R}}{v}dvd\tau=\tau\frac{\mathrm{R}}{v}dv=pdv$$

in the first of which, there being two independent variables τ and v, the integration may be performed once in regard to either, and when integrated in regard to τ we have the result as given. In the case of a perfect gas, there being no internal work, the external work pdv equals the heat expended. But if the gas be imperfect and represented by equation (k) we have, if v be constant,

$$\frac{dp}{d\tau}=\frac{\mathrm{R}}{v}+\frac{a}{\tau^2v^3}$$

and

$$d\tau\frac{dp}{d\tau}dv=\left(\frac{\mathrm{R}}{v}+\frac{a}{\tau^2v^3}\right)d\tau dv$$

and Rankine treats this by integrating the $d\tau$ outside the parenthesis, treating the quantity within as constant during the integration, in the case of the transference of enery, giving as a result

$$\tau\left(\frac{\mathrm{R}}{v}+\frac{a}{\tau^2v^3}\right)dv$$

for an element of work, both external and internal. If treated according to the ordinary rules of calculus we would have found

$$\left(\frac{\mathrm{R}}{v}\tau-\frac{a}{\tau v^3}\right)dv$$

which simply reveres the direct process giving the original expression as it ought and which would reduce finally to

$$pdv$$

which is the value for an element of the external work only. Rankine's deduction of equation (q) from equation (p) is as novel as it is original. It is the point of departure from the ordinary treatment of analysis and appears to be defended chiefly, if not entirely, on physical grounds. It is equivalent to asserting, for physical reasons, that the elementary quantity of energy which may be transferred from a body possessing heat energy to another body for a unit of energy (or temperature) equals the rate of transference of the element per unit of temperature $\left(\frac{dp}{d\tau}\right)dv$ into the absolute temperature, τ, at which the transference is made; and this assumes that each element of temperature produces its proportionate share of the work of transference. In other words, this is a repetition of the second law. Reject Rankine's second law, and this analysis is without

foundation. Had this mode of treatment emanated from a mathematician and physicist of less repute, it would doubtless have required independent proof to have secured its acceptance.

One can but admire the genius of a man who has such an insight into the workings of nature and such a command of mathematics, that he can at once express the laws of such working in so direct, simple, and comprehensive a manner as Rankine has done in this case. It is a characteristic of some of his writings that he seized an advanced principle, the mere statement of which more than half solved the problem. But these qualities do not insure immunity against errors in principle or logic. In regard to the latter may be cited his treatment of turbines, in which he presumes to treat a general case, which is in fact only a restricted one; and in regard to the former, Sir William Thomson, in the twentieth lecture on "Molecular Mechanics," says: "I do not think I would like to suggest that Rankine's molecular hypothesis is of very great importance. The title is of more importance than anything else in the work. We cannot find a foundation for a great deal of his mathematical writings, and there is no explanation for this kind of matter." In the case we are considering, however, Rankine arrives at the same result as Thomson, Clausius and other writers. Rankine applies this method to the transference of energy of any kind, in his paper "On the General Transformation of Energy," read January 5th, 1853, and similarly in another paper "On the Mechanical Action of Heat," read January 17th of the same year. These are published in the *Transactions* of the Royal Society of Edinburgh, vol. xx., also in the London *Philosophical Magazine*, and in his Miscellaneous Scientific Papers; but nowhere has he made a more complete solution of the part involving the most refined analysis than in our text. Those who understand his logic need no further statements on this point, but we are not ignorant of the fact that many students find almost an insurmountable difficulty in establishing the "symbolic expression" of the second law. And this is not surprising after the late Clerk-Maxwell, with his bright intellect, considered the law itself as "inscrutable." To such we offer the following considerations in favor of its acceptance:

Its correctness is readily verified in the case of the ideally perfect gas, as already shown, and hence for this case it is rigidly exact.

It is so nearly exact for gases considered perfect, as air, hydrogen, &c., that no error can be detected by experiment, and therefore, must be treated as strictly exact for these gases.

It is correct when the pressure increases directly as the temperature. Thus if p_1 be the increase of pressure for a rise of temperature t_1, then

$$\tau \frac{dp}{d\tau} dv = \tau \frac{p_1}{t_1} dv = p dv.$$

Since $\tau \div p$ will equal $\frac{p_1}{t_1}$. This principle was used by our author in an article in *The Engineer* of June 28th, 1867, in which he sought to explain and illustrate the second law in a simple and popular manner by finding the latent heat of steam. (Miscel. Sc. Papers, p. 432.)

The second law regarded as a statement of the law of efficiency of a perfect heat engine is universally accepted, page 343 of our text. Similarly in regard to Carnot's principle. (*Phil. Mag.*, 1846, p. 313; 1856, 1, p. 215.)

Clausius says: "If the first theorem is called the *Theorem of the Equivalence of Heat and Work*, the second may be naturally called the *Theorem of the Equivalence of Transformation*." (*Phil. Mag.*, 1868, 1, p. 414.)

Its application to imperfect gases gives results that are correct within the limits of errors of observation. On this point we might say considerable, but we simply remark that the formulas which represent imperfect fluids are empirical, and are not only subject to errors, greater or less, but cannot be safely applied much beyond the range of the experiments upon which they are established. For some interesting cases, see articles 255, 256, 257, 258A of our text.

Finally, it may be accepted with confidence, because it has been obtained by different eminent scholars and by independent methods of analysis.

It is an advantage to a student, in attempting to overcome a difficulty, to be assured that the result sought is correct,

for then he has only to contend with his own methods, being certain that the difficulty exists within himself. The investigator, however, must push forward and establish himself beyond the boundaries of previous knowledge.

Returning now to the consideration of the subject, we observe that in treating the expression

$$\tau \frac{dp}{d\tau} dv,$$

the process of its generation must be recognized, that is τ is independent of $\frac{dp}{d\tau}$, and hence the latter may be operated upon independently of the former.

At the close of article 241 the author says: "which quantity is known when Q and the law of its variation of dU with Q are known;" in which we have another singular mathematical expression—that of a relation between a finite quantity Q and a differential quantity dU! This needs *interpreting*, and may readily be done by changing the form to the one last given, and the quotation should read "which quantity is known when τ (or Q) and the law of variation of p with τ are known."

Resuming equation (q) we have for the work done *at constant temperature*

$$W = \tau \int \frac{dp}{d\tau} dv \qquad (r)$$

In this expression, W is a function of τ as well as of v, and as $\frac{dp}{d\tau}$ for imperfect fluids cannot be expressed simply in terms of v, the total differential of W will be the sum of the partial differential equations regarded as functions of τ and v. The two partial differential equations are

$$\left(\frac{dW}{dv}\right) = \tau \frac{dp}{d\tau}$$

$$\left(\frac{dW}{d\tau}\right) = \tau \int \frac{d^2p}{d\tau^2} dv \qquad (s)$$

or the total differential may be expressed thus:

$$\dot{d}.W = \tau \dot{d}. \int \frac{dp}{d\tau} dv \qquad (t)$$

where the dot is used, as by the author, to express the *total* differential. This treatment of equation (r) is similar, in principle, to Lagrange's method known as the *Variation of Parameters*, which here consists in first treating $\frac{dp}{d\tau}$ as independent of τ and dependent upon v in which case the integration may be performed, and the arbitrary constant for which afterwards treated as a function of τ. This method of treating certain differential equations is explained in higher works on the calculus, such as Price's Infinitesimal Calculus, Boole's Differential Equations, and Todhunter's Integral Calculus. It will be observed that these expressions of our author are "symbolic" and as such simply *indicate* the mode of operation in the solution of particular examples. In the case of internal work done at constant temperature, equation (s), written thus:

$$(dW) = \tau \int \frac{d^2p}{d\tau^2} dv.d\tau$$

will be zero, but in other cases the amount of internal work at temperature τ for a change $d\tau$ may be finite, and will be different at different points in the scale of temperature. This principle is involved in that of specific heat to be considered hereafter.

Equation (t) being an expression for the *work* done, both external and internal, by the disappearance of heat for an elementary change of volume and temperature, it remains to find an expression for the quantity of heat producing change of temperature only which will be so much of the heat imparted to the body as is in excess of the work, both internal and external, that has been done by heat. All the heat imparted to a substance above that which disappears in doing *work* makes the substance hotter. Observation shows that the same quantity of heat communicated to equal weights of different substances will not produce the same rise of temperature. Thus, one pound of steam at 300° Fahr., mixed with ten pounds of hydrogen at 40° F. will produce a mixture of two pounds at about 74° F., but the same steam mixed with ten pounds of water at 40° will produce a mixture of two pounds at about 146° F., there being no escape of heat in either case. The thermometric measure is called the *sensible* heat. As seen from the preceding example, the same amount of heat will produce different degrees of sensible heat in different substances. The "total actual heat" defined by Rankine is the

sensible heat. The ratio of the quantity of heat which produces an increase of temperature in a unit of weight of any substance to that of the temperature in the same substance is, according to Rankine, constant for all temperatures and pressures (page 307) for a given state of aggregation, and is represented by k. This principle Clausius calls in question, and gives it as his opinion that it is variable, as, for instance, in the case of water. Physical constants, so-called, are rarely, if ever, *strictly* constant, although they are often so treated when they are known to vary, as in the case of gravity for which we use $g=32.2$ except in cases where the problem demands greater refinement, and if they are constant their *exact* value is as rarely found, as in the case of Joule's mechanical equivalent of heat. The real specific heat of substances is constant as defined by Rankine within the limits of errors of observation, and hence must be treated as strictly constant until shown to be otherwise. Granting Rankine's symbolical expression of the second law and his principle of specific heat, his first general equation of thermo-dynamics may be written directly without intermediate analysis. For the heat necessary to increase the temperature an amount $d\tau$ will be

$$d\mathrm{H}=kdt \qquad (u)$$

which being expressed in foot-pounds and added to the heat disappearing in doing work produced by an elementary change of volume and temperature, equation (t), will give the total heat producing both changes simultaneously, or

$$d.\mathrm{H}=kd\tau+\tau d.\int\frac{dp}{d\tau}dv \qquad (\mathrm{A})$$

$$=kd\tau+\tau\int\frac{d^2p}{d\tau^2}dv.d\tau+\tau\frac{dp}{d\tau}dv \qquad (\mathrm{B})$$

which is equation (2) page 312 of the text. Equation (A) may be written

$$d.\mathrm{H}=\mathrm{J}k'd\tau+\tau\left(d\tau\frac{d}{d\tau}+dv\frac{d}{dv}\right)\int_{v_1}^{v_0}\frac{dp}{d\tau}dv \qquad (\mathrm{C})$$

as given by our author in the *Philosophical Magazine*, 1856, (2), page 103. In the last equation J is Joule's equivalent and k' the real specific heat compared with water, and $\mathrm{J}k'=k$ is the real dynamical specific heat.

Equation (A) may also be written, as in the text,

$$d.\mathrm{H}=kd\tau+\tau d.\mathrm{F}=\tau d\varphi \qquad (\mathrm{D})$$

where

$$d.\mathrm{F}=\left(\frac{d\,\mathrm{F}}{d\tau}\right)d\tau+\left(\frac{d\,\mathrm{F}}{dv}\right)dv$$

and

$$\mathrm{F}=\int_{v_1}^{v_0}\frac{dp}{d\tau}dv$$

The expression for $d.\mathrm{F}$ is written in the above form in one of Rankine's original papers, and in our text this form is implied.

The terms "heat potential," heat "factor," "metabatic function," and "thermodynamic function," used by our author in this connection, remind us of a remark of Sir William Thomson in his twentieth lecture on "Molecular Dynamics" before referred to, where he said, "Rankine was that kind of a genius that his names were of great suggestiveness; but we cannot say that always of the substance."

Clausius writes the partial differential equation

$$d\mathrm{H}=\left(\frac{d\,\mathrm{H}}{d\tau}\right)d\tau$$

to express the quantity of heat due to an elementary increase of the temperature of a substance, in which if $\left(\frac{d\,\mathrm{H}}{d\tau}\right)$ be constant it cannot be integrated unless it is a *known* function of τ. If it be constant it may be represented by k as above. Equation (A) can be used in any particular case only so far as the function is continuous, and hence is restricted to that of a constant state of aggregation.

Representing the sum of the coefficients of $d\tau$ in equation (B) by C_v, and dividing through by τ the equation becomes

$$d\varphi=\mathrm{C}_v\frac{d\tau}{\tau}+\frac{dp}{d\tau}dv,$$

which is the form of the general equation given by Clausius when τ and v are the independent variables (equation 21, page 206 of Brown's translation). This equation cannot be integrated unless C_v is either constant or a function of τ, and $\frac{dp}{d\tau}$ also a constant or capable of being expressed as a function of v.

A discussion of equation (B) enables

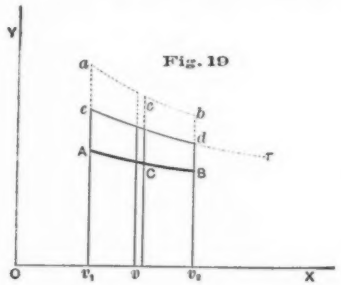
one to see more clearly the meaning of each term.

a. Assume the temperature constant. Then will $d\tau = o$, and the equation becomes

$$dH = \tau_1 \frac{dp}{d\tau} dv$$

$$\therefore H = \tau_1 \int_{v_1}^{v_2} \frac{dp}{d\tau} dv$$

which is a measure of the heat that must be supplied from an external source in



order to maintain the constant temperature τ_1 while the fluid expands from v_1 to v_2, and since all the heat supplied has been transmuted into work, internal as well as external, it is called *the latent heat of expansion* (page 309), or the heat which disappears in doing work. The case is represented graphically by Fig. 19, in which the ordinate vC represents the pressure p, when the volume is Ov, and the ordinate $vc = \tau_1 \frac{dp}{d\tau}$ is such that when multiplied by dv will give an element of work both external and internal, and the integral of the expression between the limits v_2 and v_1 multiplied by τ_1 gives the entire work, $v_1 v_2 ba$ done during the expansion. The ordinates to the line AB represent the external pressures for the corresponding volumes.

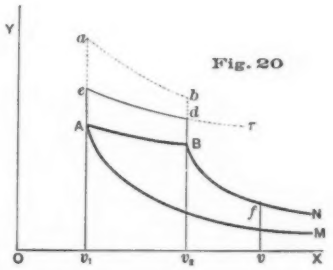
If through A and B respectively the adiabatics AM and BN be drawn, Fig. 20, then will the indefinitely extended area MABN represent the heat communicated to the substance from an external source while doing the external work $v_1 A B v_2$ at constant temperature, as will be shown hereafter, and from this fact it follows that the area between the adiabatics MABN is greater for an imperfect than for a perfect gas, the same external work being done with each substance.

Having the equation of the fluid, the relative height of the line ab may be determined. Thus in the case of carbonic acid gas we have:

$$p = R\frac{\tau}{v} - \frac{a}{v^2\tau} = v_1 A \qquad (v)$$

If this gas were perfect, we would have $a = o$, and

$$p = R\frac{\tau}{v} = v_1 e,$$



and $e\tau$ would be the isothermal and $v_1 e$ the pressure for a perfect gas.

From equation (v) we have:

$$R\frac{\tau}{v} - p = \frac{a}{v^2\tau} = Ae.$$

When τ is constant the term $\frac{a}{v^2\tau}$ decreases as v increases, hence the line of pressures, AB, approaches the isothermal line $e\tau$, and ultimately becomes an asymptote to it.

The ordinate $v_1 a$ which represents the pressure involved in doing both external and internal work, will be

$$\tau\frac{dp}{d\tau} = p + \frac{2a}{v^2\tau} \qquad (w)$$

$$\therefore Aa = \tau\frac{dp}{d\tau} - p = \frac{2a}{v^2\tau},$$

so that for this fluid the distance ea above the isothermal equals Ae the distance of the line of external pressures below the isothermal. The line ab will also approach the isothermal and ultimately be an asymptote to it. In an adiabatic expansion the temperature decreases while the volume increases though not at so rapid a rate, and the distance between

the isothermal corresponding to any pressure, and the lines of pressures does not diminish so rapidly as in the preceding case.

By means of equations (v) and (w) we may compute both the internal and external work for this gas at constant temperature. For the external work we have by means of equation (v),

$$\int p dv = R\tau \int_{v_1}^{v_2} \frac{dv}{v} - \frac{a}{\tau} \int_{v_1}^{v_2} \frac{dv}{v^2}$$

$$= R\tau \log. \frac{v_2}{v_1} - \frac{a}{\tau}\left(\frac{1}{v_1} - \frac{1}{v_2}\right)$$

which shows that the work performed during the expansion is less at constant temperature for an imperfect than a perfect fluid. It must not be inferred that this result conflicts with the principle taught by the masters of this subject—that the work done by heat is independent of the nature of the working fluid—for the latter principle is restricted to work done in a cycle, while the above analysis applies only to expansion.

For the total work, both external and internal, we have, by the aid of equations (w) and (v),

$$\int_{v_1}^{v_2} \frac{\tau \frac{dp}{d\tau}}{dv} dv = R\tau \int_{v_1}^{v_2} \frac{dv}{v} + \frac{a}{\tau} \int_{v_1}^{v_2} \frac{dv}{v^2}$$

$$= R\tau \log. \frac{v_2}{v_1} + \frac{a}{\tau}\left(\frac{1}{v_1} - \frac{1}{v_2}\right)$$

and the difference between these, or

$$\frac{2a}{\tau}\left(\frac{1}{v_1} - \frac{1}{v_2}\right)$$

gives the internal work.

If $v_2 = \infty$, we have

$$\frac{2a}{\tau v_1}$$

for the total internal work at constant temperature for an infinite expansion, which is finite, while the external would be infinite. The last expression is a function of the temperature and initial volume only.

b. Consider the volume constant.—Then will $dv = o$, and the third term of equation (B) disappears, but the second term will not vanish for the same condition, since dv is there under the integral sign and may be considered in the sense of an integration performed, and the equation becomes

$$dH = k d\tau + \tau \int \frac{d^2p}{d\tau^2} dv . d\tau$$

$$\therefore \frac{dH}{d\tau} = k + \tau \int \frac{d^2p}{d\tau^2} dv = C_v \qquad (x)$$

which is the rate at which heat must be supplied to a pound of the substance per *unit* of temperature, in order to raise the temperature one degree, and hence is called the specific heat at constant volume (v and τ being the independent variables). For a perfect gas the integral part of the expression is zero, hence, by integration,

$$H = k\tau \qquad (y)$$

or the temperature increases directly as the quantity of heat supplied. This reveals no additional truth, but simply reduces the expression back to the assumption made by the author in the case of a perfect gas in a constant state of aggregation. According to Equation (x) the term reprepresenting the real specific heat (or real dynamic specific heat if measured in foot-pounds) will be constant, and the *apparent* specific heat will exceed this by the amount of heat necessary to do the internal work at constant volume.

c. Let there be no transmission of heat and no external work done. Then, in equation (B), will H and $dH = o$, v be constant and $dv = o$, and the equation becomes

$$o = k d\tau + \tau \int \frac{d^2p}{d\tau^2} dv . d\tau$$

and integrating

$$\left(k + \tau \int \frac{d^2p}{d\tau^2} dv\right)\tau = \text{constant},$$

or the temperature will remain constant.

d. Let there be no transmission of heat and external work be done. Then will $dH = o$, and we have

$$o = \left(k + \tau \int \frac{d^2p}{d\tau^2} dv\right) d\tau + \tau \frac{dp}{d\tau} dv$$

which is the differential equation of an adiabatic when τ and v are the variables, p being eliminated by means of the equation of the fluid (equation 1, page 319). The last equation cannot be integrated for the general case of imperfect gases. If expansion be adiabatic the pressure and temperature both vary, the three quantities v, p, τ, being so related that a

definite change in one necessitates a definite change in both the others. Let the gas be perfect then

$$p=\mathrm{R}\frac{\tau}{v},\quad \frac{dp}{d\tau}=\frac{\mathrm{R}}{v},\quad \frac{d^2p}{d\tau^2}=o,$$

and the preceding equation becomes

$$k\frac{d\tau}{\tau}+\mathrm{R}\frac{dv}{v}=o \qquad (z)$$

Let the initial temperature in the state B be τ_2, corresponding to the volume $Ov_2=v_2$, and the corresponding values in the state b be τ and v_1, Fig. 21, and integrating between these limits we have

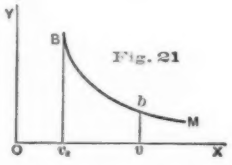


Fig. 21

$$k\log.\frac{\tau_2}{\tau}+\mathrm{R}\log.\frac{v_2}{v}=o$$

$$\therefore\ k\log.\frac{\tau_2}{\tau}=\mathrm{R}\log.\frac{v}{v_2}$$

$$\therefore\qquad \frac{\tau_2}{\tau}=\left(\frac{v}{v_2}\right)^{\frac{\mathrm{R}}{k}}=\left(\frac{v}{v_2}\right)^{\gamma-1} \qquad (az)$$

Eliminating τ and τ_2 by means of the equations

$$pv=\mathrm{R}\tau$$

$$p_2v_2=\mathrm{R}\tau_2$$

gives

$$\frac{v}{v_2}=\left(\frac{p_2}{p}\right)^{\frac{1}{\gamma}} \qquad (bz)$$

which is the equation of the adiabatic, equations (4) page 319 of the text. We may now find an expression for the area $v_2\mathrm{B}bv$, Fig. 21, which represents the work done during an adiabatic expansion for a perfect gas. Equation (z) becomes

$$k\int_{\tau}^{\tau_2}d\tau=\int_{v_2}^{v}\tau\frac{dp}{d\tau}dv=\int_{v_2}^{v}pdv \qquad (cz)$$

and substituting the value of p from (bz),

$$k\,(\tau_2-\tau)=\frac{p_2v_2^{\gamma}}{1-\gamma}(v^{1-\gamma}-v_2^{1-\gamma})$$

$$=\frac{p_2v_2^{\gamma}}{\gamma-1}(v_2^{1-\gamma}-v^{1-\gamma})$$

the second member of which is the area $v_2\mathrm{B}bv$, and the left member is heat lost; hence the loss of heat equals the work done, as it should as before shown. If now the expansion be extended indefinitely, v becomes infinite, and according to equation (az) τ becomes zero, and the preceding equation becomes

$$k\tau_2=\frac{p_2v_2}{\gamma-1} \qquad (dz)$$

The first member is, according to equation (y), the amount of heat imparted to a perfect gas forms an external source in

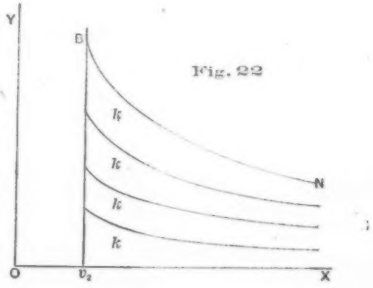


Fig. 22

raising its temperature from zero to the absolute temperature τ_2, and this equals, according to equation (dz), the indefinitely extended area $\mathrm{MB}v_2\mathrm{X}$. Let the ordinate $v_2\mathrm{B}$ (Fig. 22) be divided into as many equal parts as there are units in the absolute temperature, that is into τ_2 parts, and through each point of division an adiabatic be drawn and extended to the right indefinitely, then will the areas between any two consecutive adiabatics be equal, and if each be represented by k, the sum of all of them will be $k\tau_2$. Specific heat may be represented by a unit of the area representing heat.

For perfect gases we have

$$\frac{p_2v_2}{\tau_2}=\frac{p_0v_0}{\tau_0}$$

from which finding p_2v_2, and substituting in equation (dz), gives:

$$k\tau_2=\frac{p_0v_0}{\gamma-1}\cdot\frac{\tau_2}{\tau_0}$$

$$\therefore\ k=\frac{p_0v_0}{(\gamma-1)\tau_0}$$

which value is given on page 319 of text.

e. Specific heat of an imperfect gas.—As shown by equation (x) the expression for the specific heat in this case contains the term $\tau\int\frac{d^2p}{d\tau^2}dv$, which represents the amount of heat absorbed and stored in the body in doing internal work at the temperature τ for a change of temperature of one degree on the supposition that the *rate* of doing the internal work is uniform throughout the degree. It does not involve a change of volume—the heat thus absorbed does not affect the temperature—but disappears, as in all other cases where heat produces work. To find its value for a particular case, we again take the equation for carbonic acid gas. We have found, Equation (w)

$$\tau\frac{dp}{d\tau}=p+\frac{2a}{v^2\tau}$$

$$\therefore\ \frac{d^2p}{d\tau^2}=-\frac{2a}{\tau^2v^2} \qquad (ez)$$

and $$\tau\int\frac{d^2p}{d\tau^2}dv=-2a\tau\int_{\infty}^{v}\frac{dv}{\tau^2v^2} \qquad (fz)$$

The differentiations are performed on the supposition that τ is variable and v constant, but now the integration is to be made with τ constant and v variable. But whence this infinite limit, since the term has been produced from one containing the finite limits of expansion, as shown by equation (C).

The answer will be more clearly shown in the consideration of the more general case hereafter considered, but the fact may here be stated that since heat has been represented by an area, so here the value of the expression in equation (fz) is assumed to be an area representing an indefinite expansion at constant temperature. According to this view v now becomes an abscissa to such an *ideal* area, and not that of an *actual* expansion as appears in the expression pdv, and the use of the infinite limit at once becomes apparent. The author is not satisfactory on this point. He refers to it twice, once in our text and once in one of his original papers, and in neither case is a satisfactory explanation given, unless the one in the text be so considered.

There is probably no difficulty involved in the fact that v is constant during the differentiation. It is the case of a gas confined in an inextensible vessel—like a cylinder containing an immovable piston—the gas being heated from zero temperature or from any finite limit τ_1 to a higher temperature τ, but is impossible to find the total heat absorbed, or the internal work done from zero to τ, or even through a finite range of temperatures, as shown by Equation (fz), since τ is not a function of v only. In establishing the differential equation, however, we need only the work for an infinitesimal change of temperature, so that we may consider τ constant in (fz) in determining the coefficient of $d\tau$ of Equation (B), and the expression becomes

$$-\frac{2a}{\tau_1}\int_{\infty}^{v}\frac{dv}{v^2}=\frac{2a}{\tau^2v} \qquad (gz)$$

Whenever p in equation (v) is less than $R\frac{\tau}{v}$, the sign before equation (gz) will be negative, and since in this case the value of the second member must be *added* to k in equation (B), the infinite limit will be inferior.

In order to find a numerical value for this term it is necessary to assume definite values for τ and v. Taking $p=p_0=2116.4$ pounds, the pressure of the atmosphere on a square foot, $\tau_0=493.2°$ F., the absolute temperature of melting ice, $v_0=8.15725$ cubic feet in one pound of carbonic acid gas at the above pressure and temperature (page 229 of the text), and $a=3.42\times17264\times8.15725$, we have:

$$\frac{2a}{\tau_0^2v_0}=8.84\,\frac{17263}{(493.2)^3}=0.484 \text{ foot pounds.}$$

At 60° F.$=512.2°$ F. absolute, the volume being the same, we have:

$$\frac{2a}{\tau^2v_0}=6.84\,\frac{17263}{(521.2)^3}=0.435 \text{ foot pounds.}$$

The real dynamic specific heat of this gas being 132 foot pounds, equation (B) becomes

$$d\,\mathrm{H}=(132+0.435)d\tau+\tau\frac{dp}{d\tau}\,dv.$$

The second term in the parenthesis is so small compared with the other that it may be omitted for ordinary ranges of temperature. It is less than the limits of the errors of observation. Rankine treats it as constant, and then rejects it on account of its relatively small value (see remark on page 317 of the text).

This mode of treatment, however, is not theoretically correct, and very small values of τ and v give abnormally large results. Fortunately, we have no occasion to use values of τ so small as 1°, 10°, 100°, or even 300°, nor of v less than 3 or 4 cubic feet, and even with these extreme values the result will still be so small that it may safely be rejected. This part of the analysis is very refined, and we seriously question whether it accurately represents nature, and it is a consolation to know that it may be discarded in practice. The most important term, in dealing with imperfect fluids, is the third one in equation (B) and involved in the part $\tau \frac{dp}{d\tau}$.

The result as to pressure, volume and temperature may be conceived to be produced by compressing the gas from an indefinitely large volume along the adiabatic MA, Fig. 23, doing external work MAv_1X upon the substance, the internal work due to compression $MAam$, which will be negative, and conceived to be due to the attractions of the particles for each other, and therefore assisting in producing compression, and the internal work maa_1m_1 due to an increase of the temperature. Or, if the substance be expanded indefinitely from the state A, it will do the same amount of positive external work, and the internal work previously done by increasing the temperature will now be transmuted again into heat, which ultimately is conceived to become zero, being expended in doing work by an indefinite expansion. Since the adiabatic AM is determined by the relation between the volumes and pressures only, the work done by adiabatic expansion will be a function of the pressure and volumes only, or of the temperature and volume only. The *internal* work done by an adiabatic expansion is partly at the expense of actual heat, represented by the area $MAam$, and partly by the heat which became latent or potential on account of the increase of temperature, and represented by maa_1m_1.

Let $$\tau \int_{\infty}^{v} \frac{d^2p}{d\tau^2}\, dv = \mathrm{P} \qquad (hz)$$

then will the integral of equation (B) be

$$\mathrm{H} = (k+\mathrm{P})(\tau_2 - \tau_1) + \int_{v_2}^{v_1} \tau \frac{dp}{d\tau}\, dv \qquad (\mathrm{E})$$

the last term of which cannot generally be integrated since the pressure p may not only be arbitrary, but $\tau \frac{dp}{d\tau}$ not a function of v only.

Let Ov_1, Fig. 23, be the volume of a pound of the fluid without heat or pressure, to which heat being communicated, the pressure will be raised to v_1A, while the isothermal representing the temperature passes through a, AM an adiabatic, am an adiabatic through a as for a perfect gas, and a_1m_1 a line following the general course of am, and becoming an asymptote to it.

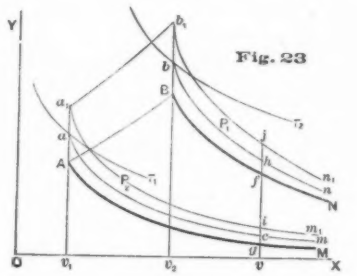


Fig. 23

From the state A let the substance expand from v_1 to v_2 and receive heat from an external source raising its temperature from τ_1 at A to τ_2 at B, doing the external, or visible work, v_1v_2BA, and the internal work due to expansion $AB b_1a_1$; and from the state B expand adiabatically doing the ideal external work NBv_2X and the internal work NBb_1n_1. The area nbb_1n_1 represents the latent heat due to raising the temperature from zero to τ_2. The several terms of equation (E) will be

$$k\tau_2 = nbv_2\mathrm{X}$$
$$\mathrm{P}\tau_2 = nbb_1n_1$$
$$k\tau_1 = mav_1\mathrm{X}$$
$$\mathrm{P}\tau_1 = maa_1m_1$$
$$\int \tau \frac{dp}{d\tau} dv = v_1v_2b_1a_1.$$

Hence Equation (E) is represented by the entire area of the figure $n, b, a, v_1\mathrm{X}$ less the area $m_1a_1v_1\mathrm{X}$, or

$\mathrm{H} = n_1b_1a_1m_1$ indefinitely extended. (E_1)

But if the fluid be worked in the cycle v_1 to A, to B, to v_2, to v_1; or better, in the cycle MABN, the internal work will be zero, or

$$AB b_1 a_1 + NB b_1 n_1 - MA a_1 m_1 = o \quad (iz)$$

which, subtracted from the second member of the preceding equation, gives

$$H = MABN \quad (E_2)$$

for the resultant integral of equation (E), as stated by our author on page 313. But to produce this result by algebraic analysis requires a further transformation.

Adding $\int p dv$ to equation (E), and subtracting it from the same, gives

$$H = k(\tau_2 - \tau_1) + \int_{\infty}^{v} \tau \frac{d^2p}{d\tau^2} dv (\tau_2 - \tau_1) + \int_{v_1}^{v_2} \left(\tau \frac{dp}{d\tau} - p\right) dv + \int_{v_1}^{v_2} p dv \quad (E_3)$$

in which p is an ordinate to AB, and hence the last term expresses the external work performed during the expansion from v_1 to v_2 and equals $v_1 v_2 BA$. The entire internal work performed by a rise in the temperature and an increase in the volume is expressed by the second and third terms, respectively. Let $p_2 = vf$ be an ordinate to the adiabatic BN and $p_1 = vg$ to AM, then we have for the strip above BN

$$\int_{r_2}^{\infty} \left(\tau \frac{dp_2}{d\tau} - p_2\right) dv = NB b_1 n_1$$

and for that above AM

$$\int_{v_1}^{\infty} \left(\tau \frac{dp_1}{d\tau} - p_1\right) dv = MA a_1 m_1$$

and

$$\int_{v_1}^{v_2} \left(\tau \frac{dp}{d\tau} - p\right) dv = AB b_1 a_1$$

and equation (iz) gives

$$\int_{v_1}^{v_2} \left(\tau \frac{dp}{d\tau} - p\right) dv = \int_{\infty}^{v_2} \left(\tau \frac{dp_2}{d\tau} - p_2\right) dv - \int_{\infty}^{v_1} \left(\tau \frac{dp_1}{d\tau} - p_1\right) dv \quad (jz)$$

The complete differential of the first term of the second member is

$$d \cdot \int_{\infty}^{v_2} \left(\tau \frac{dp_2}{d\tau} - p_2\right) dv = \left(\tau \frac{dp_2}{d\tau} - p_2\right) dv + \int_{\infty}^{v_2} \tau \frac{d^2p_2}{d\tau^2} dv \cdot d\tau,$$

the last term of which now follows naturally from the analysis, the nature of which has already been explained. We have represented it by the area nbb_1n_1. The integral of the first member, considering both τ and v as independent variables, is also the integral of the second member, or

$$\int_{\infty}^{v_2} \left(\tau \frac{dp_2}{d\tau} - p_2\right) dv = \int_{\infty}^{v_2} \left(\tau \frac{dp_2}{d\tau} - p_2\right) dv \int_{0}^{\tau_2} \int_{\infty}^{v_2} \tau \frac{d^2p}{d\tau^2} dv\, d\tau,$$

$$= -NB b_1 n_1 + nbb_1 n_1 = -NB bn, \quad (kz)$$

and this is a function of the *temperature* and *volume* only, and hence implicitly of the *pressure* and *volume* only. The last term of equation (jz) may be expressed in the same form.

In regard to the signs of the terms of Equation (kz) we observe that we consider

$$\int_{v_2}^{\infty} \left(\tau \frac{dp}{d\tau} - p\right) dv$$

as positive, and by inverting the order of the limits it becomes negative, and we have written it $-NB b_1 n_1$; and in regard to the other term we have previously shown why it should be positive as it stands. Or, regardless of the resulting signs of the values following any order of integration, it will be observed that the result sought is the difference of the areas $NB b_1 n_1$ and $nbb_1 n_1$, and that this result is, ultimately, to be subtracted from nbv_2X.

Let

$$\int_{\infty}^{v_2} \left(\tau \frac{dp_2}{d\tau} - p_2\right)_{\tau_1 v} dv = -S_2 \quad (lz)$$

then

$$-S_2 = -NB b_1 n_1 + nbb_1 n_1 \quad (mz)$$

and similarly,

$$-S_1 = -MA a\, m_1 + maa_1 m_1 \quad (nz)$$

and these several equations finally reduce (E_2) to

$$H = k\tau_2 - S_2 + \int_{v_1}^{v_2} p dv - (k\tau_1 - S_1) = MABN \quad (E_4)$$

A discussion of this equation should give essentially the same results as before found.

a. Let no heat be supplied. Then

$H=0$, and work will be done by an adiabatic expansion, and in Fig. 24 we have:

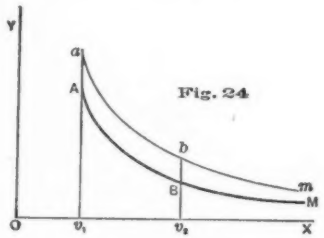


Fig. 24

$$k\tau_1 = mav_1X,$$
$$S_1 = MA am,$$
$$\int pdv = v_2v_1AB,$$
$$k\tau_2 = mbv_2X;$$
$$S_2 = MB bm,$$

hence, (Equation E_4),

$$\int_{v_2}^{v_1} pdv = -\int_{v_1}^{v_2} pdv$$
$$= (k\tau_2 - S_2) - (k\tau_1 - S_1),$$
$$= MBv_2X - MAv_1X,$$
$$= -v_2BAv_1.$$

b. Let no external work be done. Then $\int pdv = o$, and v_2 falls on v_1, and all the work will be internal during the increase of temperature. The equation becomes

$$H = k\tau_2 - S_2 - (k\tau_1 - S_1) \qquad (oz)$$

If $\tau_1 = o$, and $S_1 = o$, this becomes

$$H = k\tau_2 - S_2 \qquad (pz)$$

But to heat a perfect gas to the temperature τ_2 requires an amount of heat represented by $k\tau_2$, and it has been previously shown that to heat an imperfect gas to the same temperature requires a larger amount of heat, whereas, according equation (pz), it *appears* to require less in the latter case. But, according to equation (jz), the left member will be zero for this case, and the right member will give, Fig. 23,

$$NBb_1n_1 = MAa_1m_1,$$

(observing, however, that for this case v_1A will fall on v_2B), and this in equations (mz) and (nz) gives

$$-S_2 + S_1 = nbb_1n_1 - maa_1m_1,$$

if S_1 be zero, we have

$$-S_2 = mbb_1m_1,$$

and equation (pz) becomes

$$H = k\tau_2 + mbb_1m_1,$$

a result which agrees with previous analysis, and is consistent with the principles of the subject. This part of the discussion would be facilitated by substituting the values of S_1 and S_2 of equations (mz) and (nz), for S_2 become positive when no external work is done.

c. Let the temperature be constant. Then $\tau_1 = \tau_2$ and equation (E_4) becomes

$$H = \int_{v_2}^{v_1} pdv - S_2 + S_1.$$

In this case the last terms of equations (mz) and (nz) are equal, and we have

$$-S_2 + S_1 = -NBb_1n_1 + MAa_1n_1.$$

Professor Tait, an ardent admirer of our author says of him: "He was ambitious; that is obvious from the number and variety of his books and papers, and the quite unnecessary display of symbols in several of his less popular writings." But there was not an unnecessary display of symbols in explaining article 247 of the text. More explanations on his part would have been acceptable to the student.

In regard to article 248, in which p and τ are the independent variables, we regret that the author has not left a solution which is accessible, for we anticipate that it would contain some master strokes of analysis. A solution is given in McCulloch's "Mechanical Theory of Heat," in accordance with Rankine's suggestions but even when separated from other analysis in the work it is rather lengthy. Clausius carries the two cases together—first with v and τ as independent variables; and, secondly, with p and τ as independent variables—but the general solution is somewhat lengthy. We offer the following special solution:

Let W = the energy of the body, including the heat energy and the internal work.

$U = \int pdv$ = the external work.

H = the heat imparted to the substance; then

$$d\mathrm{H}=\tau d\varphi=d\mathrm{W}+pdv \qquad (1)$$

$$\therefore\ \tau\frac{d\varphi}{dp}=\frac{d\mathrm{W}}{dp}+p\frac{dv}{dp} \qquad (2)$$

$$\tau\frac{d\varphi}{d\tau}=\frac{d\mathrm{W}}{d\tau}+p\frac{dv}{d\tau} \qquad (3)$$

in which p and τ are the independent variables. Eliminate W from these equations; to do which differentiate (2) in reference to τ, and (3) in reference to p, and subtract, giving

$$\frac{d\tau}{d\tau}\cdot\frac{d\varphi}{dp}+\tau\frac{d^2\varphi}{dp\,d\tau}=\frac{d^2\mathrm{W}}{dp\,d\tau}+\frac{dp}{d\tau}\cdot\frac{dv}{dp}+p\frac{d^2v}{dp\,d\tau}$$

$$\frac{d\tau}{dp}\cdot\frac{d\varphi}{d\tau}+\tau\frac{d^2\varphi}{dp\,d\tau}=\frac{d^2\mathrm{W}}{dp\,d\tau}+\frac{dp}{dp}\cdot\frac{dv}{d\tau}+p\frac{d^2v}{dp\,d\tau}$$

$$\therefore\quad\frac{d\varphi}{dp}-\frac{d\tau}{dp}\cdot\frac{d\varphi}{d\tau}=\frac{dp}{d\tau}\cdot\frac{dv}{dp}-\frac{dv}{d\tau}.$$

Now $\frac{d\tau}{dp}$ is formed by an assumed increment in p while τ is constant, $\therefore\ \frac{d\tau}{dp}=o$, and in the second member $\frac{dp}{d\tau}$ is formed by an assumed increment in τ while p is constant, $\therefore\ \frac{dp}{d\tau}=o$; which is in agreement with Clausius process (see "Mechanical Theory of Heat," translated by Browne, page 115). We thus have the partial differential equation,

$$\left(\frac{d\varphi_2}{dp}\right)=-\frac{dv}{d\tau}$$

or

$$(d\varphi)_2=-\frac{dv}{d\tau}dp$$

The partial differential equation $\left(\frac{d\varphi}{d\tau}\right)$ directly dependent upon the temperature is, from Equation (1),

$$(d\varphi)_2=\frac{d\mathrm{H}}{\tau};$$

$$\therefore\left(\frac{d\varphi_2}{d\tau}\right)=\frac{1}{\tau}\left(\frac{d\mathrm{H}}{d\tau}\right)$$

or

$$(d\varphi)_2=\frac{1}{\tau}\left(\frac{d\mathrm{H}}{d\tau}\right)d\tau,$$

and the total differential will be

$$d\varphi=\left(\frac{d\mathrm{H}}{d\tau}\right)\frac{d\tau}{\tau}-\frac{dv}{d\tau}dp,$$

which for a homogeneous body becomes

$$d\varphi=k_p\frac{d\tau}{\tau}-\frac{dv}{d\tau}dp \qquad (\mathrm{F})$$

where k_p is the specific heat at constant pressure, and in the case of fluids is considered constant at all temperatures and pressures. The integral is

$$\varphi=k_p\log.\ \tau-\int\frac{dv}{d\tau}dp$$

Since k_p is constant for a particular substance, we may find the form of its developed expression by using a perfect gas, for which we have

$$\frac{dv}{d\tau}=\frac{v}{\tau},\quad p=\frac{p_0v_0}{\tau_0}\frac{\tau}{v}=\mathrm{R}\frac{\tau}{v}$$

$$\therefore\ dp=\mathrm{R}\frac{d\tau}{v}-\mathrm{R}\frac{\tau dv}{v^2}$$

which, substituted in (F), gives

$$d\mathrm{H}=\tau d\varphi=(k_p-\mathrm{R})d\tau+pdv$$

which has changed the equation from τ and p independent variables to τ and v. But for a perfect gas, Equation (B) becomes

$$d\mathrm{H}=kd\tau+pdv;$$

$$\therefore\ k_p=k+\frac{p_0v_0}{\tau_0}$$

and this substituted in (F) gives

$$\varphi=\left(k+\frac{p_0v_0}{\tau_0}\right)\log.\ \tau-\int\frac{dv}{d\tau}dp \qquad (\mathrm{G})$$

which is equation (1), page 314 of the text. It may also be written

$$\mathrm{J}dq=\left(\mathrm{J}k'+\frac{p_0v_0}{\tau_0}\right)d\tau-1\left(d\tau\frac{d}{d\tau}+dp\frac{d}{dp}\right)\int\frac{dv}{d\tau}dp$$

as given by the author in the *Philosophical Magazine*, 1856, (2), page 103.

THE DISTRIBUTION OF ELECTRICAL ENERGY.

From "Iron."

In his recent inaugural address, the President of the Society of Engineers, referring to the Gaulard-Gibbs system of electrical distribution, observed that the installation at the Grosvenor Gallery, and its application to a number of establishments in the neighborhood, constituted "the first practical and commercial example in England of *bona fide* house-to-house distribution of the electrical current from a central station." The importance of the subject, no less from a scientific than a commercial point of view, induces us to look somewhat further into the matter. This we are enabled to do by the light of an interesting ing brochure which has recently been issued by the National Company for the Distribution of Electricity by Secondary Generators, Limited, whose offices are at 18 Warwick street, Regent street, London. This pamphlet deals with the question of electric lighting from a general point of view, and describes the development and progress of the Gaulard-Gibbs system from its first appearance before the public to its present successful issue. Turning first to the advantages of electric lighting, it is to be observed that the great superiority of the electric light over gas as an illuminant, and the marked advantages secured by its use, both from a sanitary point of view and for the preservation of books, pictures, art decorations and metallic ornamentation generally, from the injury inflicted by gas, are so well established that it is needless to dwell upon them here. A striking example of the results of the two methods of lighting was afforded during the gas and electrical exhibition held at the Crystal Palace in 1882–83. In the south nave, which was devoted to the exhibition of gas-lighting apparatus, the trees and shrubs suffered most severely, being materially injured after the exhibition had been open for a few weeks only, whilst at its close nought remained but, for the most part, a display of shrivelled leaves and fast withering stems. On the other hand, in the north nave, where the electric light was displayed, the plants and shrubs remained green and healthy to the last; the flowers, too, showing forth at night in all their brilliancy of natural color. But, given all the manifest advantages pertaining to the use of the electric light, the problem arose how the benefits conferred by this principle of illumination were to be made to reach the general public. It is manifestly out of the question that the average householder can afford to have an engine and a dynamo machine fitted on his premises. And even where such can be afforded, the space necessary for their proper location would in most instances be wanting. And yet this is all that, as a rule, could hitherto be offered by most of the electric lighting companies. It stands to reason that, if the employment of gas had necessitated the manufacture of that illuminating agent on the premises of the consumers, its use would have been considerably restricted. It is true that there is the accumulator system, in which the batteries are charged at the works, delivered at the consumer's house, called for when the contents have been used, recharged, and returned to the consumer. But how many are there who adopt this system for ordinary, regular every-day use? Probably not one, the only patrons of this system, doubtless, being those who elect to have their salons lighted by it on special occasions. And, after all, it is only the exact method adopted in distributing coal gas to consumers in the earliest days of its public use.

A retrospective glance at the recent history of electric lighting shows that its practical introduction for general purposes in this country dates from the year 1877, when the Jablochkoff electric candle, as it was called, was first exhibited as fitted up in a warehouse and on board a ship in the West India Docks. The next step was the adoption, in 1878, of this system on the Thames Embankment, where it continued in use till 1884 From the long stretch of road illuminated by this means it was thought at

one time that the system was destined to subserve the most important purpose to which electric lighting can be applied, namely, general house-to-house illumination, the current being distributed over a given district from a central generating station. To this purpose, however, it never was and never could be applied, and the fact, moreover, remains that, although many systems of electric lighting have since been introduced, some of which are still doing good public service, not one, with the exception of the Gaulard Gibbs system, has succeeded in establishing a claim to be considered a practical distributing system, although in several instances such a claim has been seriously advanced. The main reason for this is that in every system except the Gaulard-Gibbs a primary electrical current is employed—that is, a current taken direct from the dynamo, led along a conductor just as produced, and used without undergoing any intermediate modification or change. To conduct such a current to any useful distance, and to divide it into a large number of small parts, so to speak—so as to distribute it over a large area in the form of numerous lights of moderate power—would require conductors of enormous diameter. The dimensions would be such as to preclude their use, both on account of their weight and also their cost, as they would necessarily have to be made either of copper or of bronze. The limit at which incandescence lamps can be practically lighted by any direct system is reached at 500 yards from the producing dynamo. Another disturbing element which presents itself in all direct systems is that of danger to life when a high tension current is used, as is the case when it is desired to light arc lamps over a considerable distance on a circuit not metallically closed.

The essentials of success in any system having for its object the distribution of electricity on a practical scale are the opposite of what has been stated. In fact, it can only be accomplished by the distribution, not of the electrical current itself, but of electrical energy represented by the current. It should be understood that the energy of a current is a very different thing from the current itself, inasmuch as every given current has special properties which are capable of being modified to meet varied requirements, or, conversely stated, every special purpose—such as arc lighting, incandescent or glow lighting, electroplating, and the furnishing of motive power—has to be provided for by a special current-transforming apparatus. Now, properly treated, a given primary current can be made subservient to all these purposes by means of one and the same intermediate apparatus or converter. Then, again, when produced, the distribution of this transformed current must be effected without danger to those who are using it; otherwise no system of production, however successful scientifically, can hope for public patronage. In fact, its dangerous character would prohibit its adoption, and hence it must fail commercially.

So far as present experience shows, the only system by which the conversion of primary into secondary currents can be efficiently, economically, and safely accomplished, and those converted currents satisfactorily utilised, is that of Messrs. Gaulard & Gibbs. This system of secondary generators is founded upon the results of experiments made many years ago by Ampère, who demonstrated that bobbins of insulated copper wire were influenced by electric currents being passed through them. The phenomena of induction were also studied by Faraday, and his investigations threw still further light upon the results obtained by Ampere. Proceeding to give practical effect to the experiments of Ampere and Faraday, Messrs. Gaulard & Gibbs constructed an apparatus in which the main feature was an insulated copper wire conductor of comparatively small diameter, surrounded by other finer insulated wires. These wires were coiled spirally. The main wire was connected up with a dynamo machine capable of producing an alternating current, whilst the spiral covering wire was continued to the lamps. Upon the machine being started, a primary current was produced, which, traversing the main wire, induced another or secondary current in the spiral covering wire, which current could be rendered capable of application to either arc or incandescence lamps, or to the driving of machinery. The principle upon which the system depends is that the primary and secondary

conductors shall be of equal mass and equidistant from the iron core. The secondary generator is composed of columns, and these columns are divided up into groups, and so connected as to admit of the current induced on the secondary conductors by the influence of the alternating current which traverses the primary conductor being made to develop at will different potentials—that is, the different qualities of current required respectively for arc lamps, incandescence lamps, and motive power. An important feature of the system is that a metallically closed circuit is used to convey the primary current. Hence no limit need be fixed to the electro-motive force of the current, which, on such a circuit, may be rendered absolutely free from danger.

Such is the principle of the Gaulard-Gibbs secondary generator, the first public exhibition of which took place in the Electric Lighting Exhibition, which was held in the Royal Aquarium, Westminster, in 1883. This machine consisted of sixteen parallel columns, placed vertically between a base and an entablature of wood, to which they were individually attached. Each column was formed of a hollow cardboard cylinder two inches in diameter, around which was coiled, in two layers of superposed spirals, a cable composed of a central copper wire an eighth of an inch in diameter covered with a double layer of paraffined cotton. Around this central wire, which formed the main conductor of the primary current, and completely enveloping it, were placed in parallel order six cables, each composed of eight fine copper wires similarly insulated by a double layer of paraffined cotton. By this arrangement the inductive reaction which would occur in the spirals of the primary circuit if they were placed next to each other was prevented. The columns were disposed in four groups of four each, and were so arranged that the terminals of their inductor were brought to the commutator placed in front of the apparatus, the object of which was to direct the primary current by one or more of these groups of columns. The terminals of the secondary wires were themselves conducted to four circular commutators of identical construction placed on the side of the apparatus, the object of which was to couple these terminals by means of a simple handle, either in parallel order or end to end. By means of these commutators the individual ends of each column could be connected separately or in groups to the apparatus of consumption, whether lamps or motors, which the secondary generators had to supply with a current. In the centre of each column was an iron wire core, the magnetic action of which was regulated by means of a movable brass cap or cylinder. These cylinders emerge from the upper portion of the generator, their function being to graduate the intensity of the secondary current, and therefore the intensity of the light produced at the lamps, and this it did most effectively. The brass cylinders were moved up and down, or, in other words, the intensity of the current was regulated by means of four hand-wheels just under the entablature. A striking characteristic of this apparatus was that, although traversed by currents of the highest potential, every exposed metallic part might be touched without the risk of receiving a dangerous or even an inconvenient shock.

The first practical application of the Gaulard-Gibbs system, as already stated, was made on the Metropolitan Railway in December 1883. The generating machinery, which was located at the Edgeware Road Station, consisted of a 25 horse-power steam engine, which ran at a speed of 120 revolutions per minute, and was supplied with steam from a Cornish boiler at 60 lb. pressure per square inch. The engine drove, through a countershaft, a Siemens W° alternating current machine, running at 600 revolutions per minute, and excited by a small Siemens dynamo running at 1,000 revolutions per minute, the large dynamo giving 16,000 alternations per minute. The primary wire was led from the large dynamo to the secondary generator, which supplied the current to a series of arc and incandescence lamps in the booking-office and on the platform of the station. After traversing the generator, the primary wire was carried out of the station and along the course of the line at the side of the tunnel to Notting Hill Gate station. It returned thence to Gower street, King's Cross and Aldgate, and back again to the Edgeware Road,

being intercepted by secondary generators, and the current tapped and used for lighting at five different stations altogether, including that at the Edgeware Road. The primary circuit in which these generators were placed was composed of a single wire fifteen miles in length and only one-eighth of an inch in diameter. This primary circuit was metallically closed throughout its entire length with the terminals of the dynamo machine at the Edgeware Road station. The management of the secondary generators was found to be so simple that from the first, and during the whole of the five months the system was in use on the line, the apparatus was left in the care of the inexperienced employes of the railway company. The results proved highly satisfactory, and as regards the effective work, it was shown by Dr. Hopkinson to be 90 per cent. In fact, it was practically demonstrated that the loss occasioned by the transformation of electrical energy into light did not exceed 10 per cent.

The experience gained during the practical trial of the system on the Metropolitan Railway led to several modifications being made in the form of the apparatus, although the principle remained precisely the same as in the first instrument shown at the Westminster Aquarium exhibition. The improved form of apparatus embodies the most simple and practical method of applying economically the principle involved. Further research has led to the formation of the inducing and induced circuits by means of copper discs, superposed and furnished with ear-pieces, by which they are connected together.

Considerable as was the circuit of 15 miles on the Metropolitan Railway, it was greatly exceeded in the second installation, which was carried out at the Turin Exhibition in 1884. Here electrical energy was transmitted to a distance of 25 miles from the machine along a single conductor, which formed, consequently, a circuit of twice that length, or 50 miles. Electric currents of varying potential were developed at the extremity as well as at several points on the circuit, forming an unprecedented fact in the history of electric lighting. A Siemens dynamo of 60 horse-power, supplying a current of 3,000 volts and 10 amperes, was placed in the exhibition, and the conductor, a bronze uninsulated wire one-eighth of an inch in diameter, was carried by insulators on the ordinary railway telegraph posts to Lanzo, a town at the foot of the Alps, and twenty-five miles distant by the line of telegraph posts from the exhibition. In the exhibition building several secondary generators were used for supplying electrical currents to various kinds of lamps, whilst other generators were placed at different points on the circuit for the same purpose. Thus the railway station at Turin and those at Venaria Reale and Cirié *en route* were brilliantly illuminated by means of both arc and glow lamps. The Lanzo station was similarly illuminated by arc lamps of the Siemens and the Sun types, and by glow lamps of the Swan and Bernstein patterns, tastefully distributed over the interior and exterior of the station, and fed through several columns of Gaulard-Gibbs secondary generators by currents generated 25 miles off at Turin. This installation formed the subject of long and exhaustive investigation by the international jury of the electrical section of the Turin exhibition, and thoroughly demonstrated the value of the system. The practical outcome was that, by the verdict of the jury, a prize of 10,000 fr. (out of 15,000 fr. placed at their disposal for prizes in the electrical department) and a gold medal were awarded in respect of the invention.

The most recent installation is that at the Grosvenor Gallery, which has been undertaken by Sir Coutts Lindsay & Co., Limited, and where for several months past the secondary generator system has been in operation on a gradually extending scale, having been successively applied to a number of establishments in Bond street and the neighborhood. Messrs. MacKenzie & Brougham, of 15 Great George street, Westminster, are the engineers to this installation. At the International Inventions Exhibition held in Landon in 1885, the National Company for the Distribution of Electricity by Secondary Generators, Limited, distributed by means of a Siemens dynamo current to various types of electric lamps. They were awarded by the jury a gold medal for "the successful working out of a system of electrical

distribution by induced currents." At Aschersleben, in Germany, an installation has recently been completed, and is working most satisfactorily, comprising the distribution of 200 horse-power in light over a circuit of about six miles; some of the lamps being employed to light a mine. In this case the first practical application of the system will be made to the distribution of mechanical power. The current supplied by the secondary generators is also to be used for electro-chemical purposes. The lighting of the town of Tours, in France, is about to be inaugurated, the installation of the first 200 horse-power plant and machinery having been completed. In Italy installations will shortly be completed for supplying lights to the towns of Turin and Tivoli by the company's system, and arrangements are in progress for transporting 2,000 horse power, derived from the waterfalls of Tivoli, from Tivoli to Rome, to be applied in lighting the principal part of the latter city. In the United States of America an eminent firm—Messrs. Westinghouse, of Pittsburgh—has undertaken to work the system. We have now indicated the development of this promising system, and, after an impartial consideration of the facts stated, we cannot evade the conclusion that it has made material progress—a progress which, as far as we are aware, is without a parallel in this country as regards house-to-house distribution of the electrical current.

EXPERIMENTS WITH LIGHTHOUSE ILLUMINANTS.

By E. PRICE EDWARDS.

From the "Journal of the Society of Arts."

Before entering upon a description of the experiments with lighthouse illuminants which were carried out at the South Foreland in 1884-5, I think it proper to state that it would be out of place, on the present occasion, to refer to any personal considerations which may have been connected with the question of setting these trials on foot, therefore I shall address myself solely to the practical view of the subject, and endeavor to present to you, from my own knowledge, a dispassionate and impartial account of these important experiments, and put before you the conclusions which may be legitimately drawn from them.

For the benefit of those not technically acquainted with the details of lighthouse illumination, I must make some preliminary observations of a general character.

For very many years the illumination of lighthouses has been an attractive subject for the efforts of earnest inventors, and the suggestions of fanciful speculators. I will not detain you with a recital of the numerous schemes which, from time to time, have been put forward, but will at once tell you that the only illuminating agents which have successfully borne the tests of experiment and experience, and have been found to be serviceable for lighthouse purposes, are oil, gas, and electricity. The cardinal principle in connection with the maintenance of our coast lights is certainty; there must be no breakdown of the lights between sunset and sunrise. Mariners approaching our shores at night from distant parts are almost entirely dependent upon their sure and effective exhibition. Each one must be readily and certainly recognizable, in accordance with the advertised intimations of its special characteristic. In fulfillment of this essential condition it has come to pass, by a process analogous to that of the survival of the fittest, that oil, gas, and electricity remain the only sources of light upon which complete dependence may be placed for the purposes of effective lighthouse illumination.

In continuation of these preliminary remarks it will be useful to consider the general subject under three headings:

1. The actual sources of light.
2. The mechanical means by which the light is sustained and controlled.
3. The appliances for utilizing the light produced in the manner most serviceable to the mariner.

As each of the above named divisions would, in itself, afford ample material for a paper, I must ask you to forgive my touching them with a light hand only. My object will be simply to give those of my hearers to whom the subject is unfamiliar some general notions which will make the latter portions of my remarks more intelligible to them, and to connect the general principles of lighthouse science with the investigation at South Foreland.

1.—SOURCES OF LIGHT.

Oil.—Regarding these three illuminants as mere sources of light without reference to burners, lenses, or any of the appliances used in ordinary lighthouses, we will first give our attention to oil, which is the oldest of the three, its use dating back for nearly 100 years, when it began to replace the coal fire and candle systems of the last century. For the greater part of this long period sperm oil was used, but in 1845 it was demonstrated that rape seed or colza oil could be burned as effectually and at much less cost, and the use of sperm was discontinued. In modern times mineral oil has come to the front, and threatens to supplant the vegetable oil entirely, being very much cheaper, and giving an illuminating effect almost, if not quite equal to that of rape oil. The latter is, however, still employed at isolated rock lighthouses and on board lightships, chiefly for considerations of safety. The mineral oil now used in this country is paraffin obtained by the distillation of shale, and is at present supplied with a flashing point of 154° Fahr., thus rendering it a perfectly safe oil for use in this climate. Quite recently, a mineral oil, having a flashing point above 250° Fahr., has been tested with most encouraging results, which, if corroborated by further tests, will make it very suitable for rock lighthouses and lightships, and will tend to shut out rape oil altogether, the latter being fully twice the price of the new product. It is a coincidence that vegetable should displace animal oil, and that mineral should now be about to supplant vegetable oil. With some few exceptions, which will be referred to in dealing with gas and electricity, oil is the general illuminant now used in lighthouses of the United Kingdom, as well as in all parts of the world. In this country rigorous tests are applied to ensure the oil sent to lighthouses being of the very finest quality. Both rape and paraffin must burn without requiring to be trimmed for 16 hours. Careful examination of each is made to ascertain if any acid is left in, or other deleterious compound mixed with either kind of oil. The requirements in respect of the paraffin now used are that it must have a specific gravity between .810 and .820 at 60° Fahr., with a minimum flashing point of 140° Fahr. (close test), and must distil between the temperatures of 302° and 572° Fahr. The conjunction of such qualities as are indicated by the above requirements provides an effective and, in other respects, suitable oil for burning in lighthouses.

So far as the experiments at the South Foreland are concerned, rape oil need not be taken into consideration. Paraffin of the description above referred to only was used, and may be regarded as the representative of the oil system.

An important point may perhaps be here appropriately referred to in connection with the cost of lighthouse oil. In the early stages of the discussion as to the relative advantages of gas and oil, about twelve or fifteen years ago, economical arguments in favor of gas were based on the then prices of rape oil, which were variously quoted as 4s. 9½d., 3s. 10½d., 2s. 9d. per gallon. In these days paraffin is supplied at 6d. per gallon, a fact which obviously changes the financial aspect of the comparison very considerably.

Gas.—In the year 1865, Messrs. Edmundson & Co., of Dublin, of which firm Mr. J. R. Wigham is an enlightened and enterprising member, perfected a system by which gas could be employed as a lighthouse illuminant. At first gas made from oil was employed; but subsequently cannel coal gas was adopted. This illuminant was first established at the Howth Bailey Lighthouse, shortly afterwards taken to that at Wicklow Head, and subsequently extended to seven other lighthouse stations in Ireland, and one in England.

The gas used is obtained, by the usual process of manufacture, from the best cannel coal, and gives an illuminating power much higher than that of gas made from ordinary north country coal,

such as is used in gas works of towns where a large supply is required to be distributed. Burned in the London standard Argand burner, the gas from north country coal does not give a light superior to that of sixteen candles, as required by Act of Parliament; whereas the gas made from good cannel coal, when burned in the London standard burner, yields a light almost equivalent to that of about thirty candles. For lighthouse purposes it is essential to have the best light, and therefore cannel gas has been exclusively employed, although much dearer than north country coal. The average price of cannel delivered at the lighthouses appears to range between 40s. and 50s. per ton. A quantity of furnace coal, about one-half that of the cannel coal carbonized in the retorts, is required for each gas works, and the whole manufacture has to be carried on at the lighthouse station. The cannel coal used at the South Foreland was chosen by Mr. Wigham as best adapted for the experimental gas light to be exhibited, and came from the Lesmahagow pit.

In addition to the use of cannel gas, trials were also made at South Foreland with gas obtained from mineral oil, which proved to possess an illuminating power equal to that of 46 to 50 candles. The gas-making apparatus was put up at South Foreland by Pintsch's Patent Lighting Company, as exemplifying their system of making gas, which is of a simpler character than that of cannel gas. The works are smaller, and consequently cheaper, and the operation of gas-making can be carried out by one man alone. The oil used is paraffin, not refined, and is supplied at South Foreland at about 6d. per gallon, but would be cheaper delivered in London. The oil is caused to drip on to a tray placed in the retort, where it is heated sufficiently to convert it into gas, which, after passing through some purifying operations, goes into the gas-holder. As compared with cannel gas, the higher illuminating power of Pintsch's oil gas, in conjunction with the comparative simplicity of manufacture and economy of gas-making plant, all point to its probable superiority for lighthouse purposes. The data at my disposal are not sufficient to enable me to say with certainty whether the cost per 1,000 cubic feet is less than that of an equal quantity of cannel gas, but even assuming the price to be the same in both cases, the higher illuminating power of Pintsch's gas would make it at least 25 per cent. more valuable as an illuminating agent.

During the trials at South Foreland the bulk of the comparisons were made with cannel gas, and a small proportion only with Pintsch's oil gas.

Electricity.—The next division of our sources of light has reference to electricity. This illuminant has been employed with success in certain lighthouses in this country since 1862. In France it was first used in 1863, but of late years it has received a very considerable impetus in that country. The limited application of this luminary in the United Kingdom is not due to any practical difficulties in respect of its installation, but rather to a dislike on the part of mariners of its extremely dazzling and distressing light when they are close to it. The navigable channels leading to and from our ports and harbors are mostly near land, and are often crowded with shipping; a very dazzling light shining across the navigation at such a place would be likely to prove a source of danger rather than of safety. Chiefly on this account electricity has made but slow progress as a lighthouse illuminant in this country.

In 1857 the discovery by Faraday, of magnetic induction in a coil of copper wire, was turned to practical account for lighthouse illumination by Professor F. H. Holmes, who then made the first complete magneto-electric machine. In that year trials with the newly-born electric light were commenced at South Foreland, and were continued until 1859. Then it was discontinued at South Foreland, but established at Dungeness lighthouse in 1862. After some further experience a new lighthouse on Souter Point Coast of Durham was lighted up with the electric spark, and in 1872 it was brought back as a permanency to its first home at South Foreland, and has shone there successfully ever since. In 1874 it was removed from Dungeness, because the point was low and dangerous, and mariners did not like the light in their eyes, and could not judge their distance from the point. In 1877 it was taken to the Lizard lighthouse. It is now intend-

ed to show electric light from the lighthouse on St. Catherine's Point, Isle of Wight, and from the high tower on the Isle of May, Frith of Forth.

The machines originally employed for generating the necessary electrical energy were constructed on the magneto-electric principle, which necessitates the use of permanent magnets for the induction of electricity. I have mentioned that Holmes made the first machine on this principle, and Holmes' machines are at present employed, after running fourteen years, in maintaining the lights shown from the permanent lighthouses at South Foreland. In 1876, some trials were made with various electric generators, to ascertain which kind of machine was most suitable for producing the electric light for lighthouses. The verdict was in favor of Siemens' dynamo machines, and accordingly these machines were adopted for the Lizard Station in 1877.

In consequence of some serious irregularities in the working of these machines, and because at the time Baron de Meritens, of Paris, had perfected a very powerful and in some respects novel form of magneto-electric machine, it was resolved to send one of these new generators to the Lizard, where it has worked most satisfactorily for several years. The experience gained at Lizard suggested that for the St. Catherine's station, which it had been resolved to illuminate with electricity, the De Meritens' machines should be employed, and they were accordingly ordered; but as arrangements were then being made for the South Foreland experiments, it was agreed that these machines should be sent direct to South Foreland, to be used in the trials, and to be operated by the steam-engines already established there, there being a reserve power beyond what was required for the permanent electric lights. The De Meritens machine consists of five star-like rings, fixed parallel to and a little distance from each other. Each ring carries twelve permanent magnets of horse-shoe pattern, with their poles converging towards a central horizontal shaft. Upon the shaft are mounted five brass wheels or discs, which revolve within and in front of the poles of the magnets. Each wheel carries twenty-four helices or coils on its periphery, and one revolution causes the twenty-four coils of each disc to pass the twenty-four poles of the twelve magnets in each ring, thus producing alternate currents o positive and negative electricity. The machine is worked at a speed of 600 revolutions per minute, and the result may be popularly stated thus:

Coils. Poles. Rings. Revol.
24 × 24 × 5 × 600=1,728,000 pulsations

of alternate electricity generated in one minute. The electrical energy so excited is taken off by collectors at the ends of the shaft, and conducted by leads to the lighthouse lantern. At the South Foreland the distance between the generating machines in the engine room and the electric light lantern was 850 feet, and Professor W. Grylls Adams has shown that one-third of the united energy developed was expended in overcoming the resistance of this great length of conducting wire. Had the generating machines been close to the lantern, the electric light exhibited would have been reinforced by one-third more electrical energy than actually reached it. As a matter of fact, these machines were made for the St. Catherine's station, where they will be only a very short distance from the lighthouse.

During the trials the machines were worked either singly or coupled up with two machines in series, and occasionally with three machines in quantity. The lights shown were produced by either—

One machine with an average current of 125 ampères, and E.M.F. of 51 volts,

Two machines in quantity for one arc-light with an average current of 172 ampères, and E.M.F. of 60 volts.

Two machines in series for one arc-light, with an average current of 180 ampères, and E.M.F. of 60 volts.

Three machines in quantity for one arc light, with an average current of 180 amperes, and E M.F. of 60 volts.

The three machines could not be coupled up in series, and the result of their being coupled in quantity is not so good as the two machines in series, which gave a current of 182 ampères. The high resistance with the three machines was due to the fact that the leads were not suitable for the current from three machines. It will be seen that the most effective results were obtained with two

machines coupled in series feeding one arc-light.

II.—THE MECHANICAL MEANS BY WHICH THE ILLUMINANT, WHEN PRODUCED, IS SUSTAINED AND CONTROLLED.

In the case of oil this important function is performed by the burner. I shall not occupy your time by giving an historical account of the development of the oil-burner from ancient days, but a few observations on the general principles upon which oil-burners for lighthouses are constructed may perhaps be acceptable.

It is tolerably well known that when oil is consumed in a lamp it is converted into vapor by heat, and that the oil vapor so produced is, by the application of flame, caused to combine chemically with the oxygen in the surrounding atmosphere. In point of fact, an oil-burner is analogous to a miniature gas-works, where the gas is consumed as fast as it is manufactured. An ordinary mineral oil-burner is connected with a reservoir containing oil below it by means of a cotton wick, the lower end of which is in direct contact with the oil, the upper end just above the top of the burner. By capillary action the oil creeps upward until all the wick is saturated up to the point where the oil is to be converted into vapor, the application of flame only being required to complete vaporisation and set burning. The supply of oil must be properly regulated. With heavy fatty oils, such as rape or sperm, the capillary action is not vigorous enough to bring up from a receptacle below a sufficient quantity to keep the light going, and in that case the actual level of the oil immersing the wick must be closed to the burning point. With mineral oil the level may be two or three inches below the burning point, and its capillarity will be sufficiently active to conduct it to the top. In the case of large lighthouse lamps, the main reservoir is kept at a considerable distance below the burner, and mechanical means are employed to force the oil up to the required level, and to keep it constant for either a heavy or a light oil. To make combustion perfect, and to prevent smoke and soot, a plentiful and well-regulated supply of oxygen is essential. In the latter part of the last century, Argand demonstrated practically how such a supply could be secured for a single circular-wicked lamp, and the principle then laid down has ever since been followed in the development of the construction of lamps for burning oil. In this Argand burner you see a central tube, to which air has access at the bottom; the wick surrounds this tube, and in burning gives a circular flame, fed by the air coming up the centre. The glass chimney on the outside regulates the admission of air to the outside of the ring of flame, and thus perfect combustion is effected. A further development of the principle was made by Fresnel, who produced a burner consisting of four concentric wicks, with an air space separating each wick case, and the large glass chimney enclosing the flame completed the arrangement. Sir James Douglas increased the number of rings by two, producing the six-wick burner, which is now, and has for many years been used in many English lighthouses, and was the representative oil-burner employed in the South Foreland experiments. It should, however, be mentioned that Sir James Douglass had proceeded still further, and had produced seven, eight, and nine-wick burners, constructed on an improved principle, by which the flames are compressed at the focal plane, so that their diameter is not much greater than that of the six-wick burner, while the intensity of the light is considerably enhanced. These burners were not sufficiently perfected when the experiments began, and the bulk of the comparisons were therefore made with the six-wick burner. But they now are brought into good working order, and there is every reason to believe they will, before very long, be adopted for lighthouse work, and their increased efficiency will add much to the effectiveness of the lighthouses where they are employed.

In connection with this part of the subject it is necessary to bear in mind that oil-burners require careful looking after, that glass cylinders are a necessity, and that wicks of unusual size and very superior quality have to be provided.

For burning gas, the arrangements are certainly more simple. The gas is led by pipes to the burner in the ordinary way, a cock is turned on, and the gas lighted. It then burns without requiring serious attention as long as the gas supply lasts; it requires no glass cylinders nor wicks, no

trimming, and little cleaning, all of which are points in favor of the gas system. The gas-burners used in lighthouses, and as exhibited at the South Foreland, are those of Mr. Wigham's patent. In its complete form the burner consists of five rings of gas jets, the innermost ring having 28, the next 48, the next 68, the next 88, and the outermost 108 jets, the diameter of each ring being respectively 4, 6½, 8½, 9½, and 11¼ inches. With the gas burning, this congregation of jets packed in the space of a circle 11¼ inches in diameter gives a flame of considerable intensity, to which the air has perfectly free access, there being no glass chimney surrounding it, as in the case of an oil light. This huge flame is controlled in a great measure by the draught of the flue, the lower part of which is of talc, and, with the latest improvements, as developed during the trials at South Foreland, terminating in a sharp frustum of an inverted cone, and into the lower opening of which the tongues of flame rush in, leaving naked the thickest and most intense portion. This tends to preserve the flame in a uniform shape, which object is also materially assisted by a further improvement, introduced during the trials, of a talc collar fixed upon a collar of perforated zinc, encircling the lower part of the burner. Air passes through the perforations on to the outer surfaces of the flame, and, besides assisting to control the shape of the flame, renders combustion of the gas more vigorous. The reason for employing talc is because it is transparent, and allows a good deal of light to pass through, and strengthen the general illuminating effect, which would be lost if the cases and collars were made of an opaque material. From the blaze of 108 jets, the flame can readily be reduced to that of either 88, 68, 48, or 28 jets. The facility with which this can be accomplished is unquestionably one of the merits of this Wigham gas-burner, the mercury joint for each segment being a specially ingenuous arrangement.

Two well-known gas-burners were sent for trial at South Foreland, one the patent 6-ring burner of Mr. Sugg, the other a large size Siemens' regenerative burner. So far as the working of these burners under ordinary conditions is concerned, there is no fault to find with them, but as they proved to be unsuitable for lighthouse purposes, I need not dwell upon them.

Sir James Douglass' 6 and 10 ring gas burners, constructed on principles similar to those of his improved oil burners before described, gave results so satisfactory in the trials, that they must not be passed by. Instead of from jets, as used by Mr. Wigham, the gas issues from surface holes in concentric rings, and each ring forms a complete cylinder of flame, fed on both sides by the air ascending the spaces separating the rings. As in the oil burners, the rings of flame are compressed to the smallest diameter possible at the focal plane. No talc cone or collar is required for Sir James Douglass' burner, but a glass cylinder is necessary to preserve the shape of the flame, by regulating the air supply to the external surface of the outermost ring of the flame.

We now come to the arrangements for the electric light. Assuming the requisite current to be brought with uniform steadiness to the lighthouse lantern, by suitable conducting wires or leads, the regulation and control of the arc light produced between two carbon terminals are mainly dependent upon the action of the lamp or regulator, the delicate and ingenious mechanism of which keeps the carbon points as nearly as possible the same distance apart. The carbons originally used were supplied by Baron de Meritens, and were square in section, made up of a number of smaller square carbons, the entire bundle being 40 m.m. square. The heat caused the metallic bands by which the carbons were bound together to melt, and the consequence was that the small carbons frequently fell out while the light was being exhibited. Other carbons, circular in section, and solid throughout, 30 and 40 m.m. in diameter, were also tried; but those which gave the best results in the trials, and were used most frequently, were the Berlin core carbons, supplied by Messrs. Siemens, 40 m.m. in diameter, and with a core of graphite running through the centre. With alternating currents the electric arc can generally be maintained with a fair amount of steadiness with carbons that are tolerably homogeneous in their composition, but there is always a liability to momentary

fluctuations, caused perhaps by the current seeking to make its exit by the direction of least resistance, and thus selecting the weakest parts of the carbon. The incandescence is thus liable to be transferred from side to side, and this gives rise to the appearance of momentary fluctuations. This, however has not been found to be a very serious drawback on the whole; indeed, in one sense, it may be advantageous, as conferring a marked individuality upon the electric light, enabling it to be more easily recognized. The Berlin carbons, with their graphite core, were found to burn with exceptional steadiness, possibly because the centre core affords the current an easier and consequently more regular course.

It may be mentioned that some 50 m.m. carbons were burnt in the engine-room close to the generators, with the full current of two machines in quantity without loss; the result being a current of 400 ampères with a low E. M. F. of 45 volts only.

Before proceeding to the consideration of the third division of the subject, it is desirable to make reference to what is known as the superposing system of lights. This was first introduced by Mr. Wigham, in connection with his gas system, by placing in a lighthouse lantern two, three or four burners vertically over each other, with a distance of three or four feet between them. By this means a column of light of great power is obtained, which it was supposed would rival the strongest electric light, and thoroughly eclipse oil. Without reference to any patent right in connection with this matter, which is not only beside the question of the relative merits of the illuminants, but has, I believe, been completely disposed of since the point was brought forward, the question naturally arose—can this method of piling up lights be applied equally well to electricity and oil? No doubt at all existed as to electricity, but as regards mineral oil, it was feared that its tendency to give off inflammable vapor at high temperatures would prevent the placing of such lights at short distances above one another, as the oil might become dangerously heated. Sir James Douglass, however, effectually disposed of any doubt on the subject by putting up three mineral oil burners one above the other, in the oil lantern, at South Foreland, each lamp being fed from one reservoir placed below the floor of the lantern, and the oil being, by suitable pressure and regulation, forced up the respective burners by pipes, and maintained at the necessary constant level. It is important to note that only three oil burners were superposed, while four gas burners were superposed in an equal vertical space. This will show that the oil burners were separated by greater distances than the gas lights were. The iron chimneys which carry off products of combustion and regulate draught in the case of the oil lights were cased with asbestos cloth and silicated cotton wool, to check radiation of heat from the iron surfaces; thus the heat was kept down very successfully in this lantern, and from the experience gained at South Foreland there is no doubt that four oil lights could have been as safely maintained as three. The electric lights were also arranged to be superposed, but with three lights only, as with the oil lanterns. The terms used for describing the different order of superposition, are biform, triform, and quadriform, representing the superposition of two, three and four lights respectively. It is not necessary to enter into further details concerning this method, but future references to biform, triform and quadriform will now be intelligible to those who have not been familiar with the subject.

III.—THE APPLIANCES FOR UTILISING THE ISSUING RAYS IN THE MANNER MOST SERVICEABLE TO THE MARINER.

I must again ask the indulgence of the audience in dealing with this part of my paper. Of necessity I must trouble you with some further elementary details, in order to make the whole matter clear.

With any of the illuminants of which I have spoken, burning under the most favorable conditions, and radiating light in all directions, it is clear that some provision must be made for using the issuing rays to the greatest advantage for the purpose required. The light is wanted by the sailor to shine upon the sea; but many rays, if they followed their ordinary course, would go up into the sky; many others would fall on the floor of the lantern. In the case of a

lighthouse on shore, many rays would, under ordinary circumstances, go landward. In none of these directions is light wanted to be sent for the sailor's benefit. It has, therefore, been necessary to devise a method of utilizing such diverging rays. At first this was accomplished by metallic reflectors, and a considerable amount of success was and is still attained by this method. I need not enter into details respecting the principles of reflection; the subject is too well known. But in 1821, the celebrated Augustin Fresnel perfected an arrangement of glass lenses which, with a single large burner, accomplished the object in view much more effectively and conveniently than with a number of small burners with reflectors. Fresnel, in conjunction with Arago, had invented an oil burner with four concentric wicks, the diameter of the flame being $3\frac{3}{8}$ inches. This, however, he placed in the center of a system of lenses and prisms built up at the proper focal distance around it, so that nearly all the light rays emitted were received upon some part or other of the inner surface of the lenticular structure, the lenses and prisms being so adjusted that, by the well understood action of refraction, the rays were caused to issue from the other side of the glass in a consolidated beam, illuminating only the sea area between the distant horizon and the near shore.

For a fixed light required to show continuously with equal effect over a given arc or circle, vertical condensation only is requisite, the rays being allowed to diverge horizontally without restriction. For this purpose a central refracting belt is employed, with rows of totally reflecting prisms above and below running parallel to it. The proper adjustment of this apparatus causes a beam to issue which illuminates the sea area within the horizon in a constant manner.

For a revolving or flashing light it is necessary to cut up this all round continuous beam into segments. As before, the rays must be condensed vertically, but in addition they must be condensed horizontally in bundles, leaving dark spaces between. In this case the apparatus is polygonal, and a condensed beam issues from each side or panel. Instead of a lenticular belt all round, each panel has an annular lens with concentric refractors. All the rays falling upon the inner surface of this lens are refracted, and issue as a condensed and independent beam for each panel. The upper and lower prisms in each panel are curved so as to coincide with the concentricity of the central lens. The rays being squeezed or condensed into bundles, dark spaces are left between them. On the whole glass apparatus being made to revolve, beams of light striking the sea area within the horizon, followed by intervals of darkness, succeed each other with regularity.

The flame of Fresnel's 4-wick burner is the basis of our present dioptric system. Six orders of lights were instituted in Fresnel's time, the first order being specially adapted to the dimensions of the 4-wick flame, so that the lenticular instrument should receive all the rays emitted from such a flame. For second order lights, the dimensions of the flame of a 3-wick lamp determined the radius, focal distance, &c., of the lenses employed, and so on. But since that time the 6-wick burner has come into use, 7, 8 and 9-wick burners are on the threshold, and nearly all Mr. Wigham's gas burners, as well as those of Sir James Douglass, have larger flames than Fresnel's 4-wick oil burner. Again, the electric light, with a smaller luminous centre than Fresnel ever contemplated for a lighthouse illuminant, has come into action, so that in point of fact, the orders of apparatus as established by Fresnel, are not adapted to the large and small flames used at the present day. This anomaly is in a fair way of being set right, for Messrs. Stevenson, the eminent lighthouse engineers of Edinburgh, have recently designed a lens of larger radius adapted to an illuminant of increased diameter, and have obtained some striking results with a single Douglass 10-ring gas burner against biform 108 jets.

It remains for me now to explain to you what were the lenticular arrangements employed to give the best results for each lighting system tested at South Foreland. It will be understood from what I previously said, that besides the single light of each system, provision was made for showing the electric light in biform and triform arrangement; that gas could be exhibited in biform, triform,

or quadriform; and that oil was provided to show biform and triform only. Consequently, for the electric and oil lights three sets of lenses were required to be mounted in each lantern, and for the gas light four sets were necessary. By the term sets of lenses, I mean one lens arrangement for exemplifying a fixed light, the other for showing the condensed beam of a revolving light. Lenses being very costly articles, it was necessary to have certain regard to economy, consistent with an effective illustration of the value of lenses in connection with the lights to be exhibited. Therefore, one panel only of a fixed belt, and one annular lens of a revolving apparatus, without upper and lower prisms in any case, were provided for each light of each system, the quality of the light issuing from a portion of the apparatus being exactly the same as though the entire apparatus were employed, the only essential point being, that in judging the value of the light, the observer should take care that he is in the path of the beam.

The three towers which were erected at South Foreland for the exemplification of the three systems, were 180 feet apart, and marked respectively A, B, and C. A was appropriated for the electric light; B for the gas system as developed by Mr. Wigham; and C for the oil system and the Douglass gas burners.

In lantern A there were three electric lamps on three stages, and for each lamp was provided a panel of a fixed apparatus of the second order, consisting of a segment of the central belt with seven smaller segments above it and seven below it. The chief reason for using the second order apparatus appears to be that, as Sir J. Douglass practically observes, it affords just enough space for a fairly fat light-keeper to get inside and manipulate the lamps. A third, or even further order apparatus, would have been sufficient, although the luminous area has considerably increased, since the early days of the electric light, where carbons of small sections were used. For exemplifying the revolving beam, an exactly similar panel was used for each light to condense the rays vertically, and in addition four vertical refracting prisms were fixed on the outside of this panel, and caused to issue a condensed beam of great power. It may here be mentioned that, as the divergence of this beam horizontally was very small (30° condensed to 5°), it was necessary to take precautions to insure observers being in its path. In the superposed arrangement the distance separating the three lights was 7 feet, and the space between the lenses 4 feet.

In lantern B the four lights had each panels for exemplifying a fixed and revolving light. For the former, each light was furnished with a segment of the lenticular belt of a first order apparatus without upper and lower prisms. For the revolving light, four first order lenses of annular construction were supplied, each subtending a horizontal angle of 60°. The beautiful lenses of French manufacture were very considerately lent for use in the experiments by the Commissioners of Irish lighthouses. They were intended for and are now fixed up at the lighthouse on Mew Island, coast of Ireland. It should be observed that the four gaslights themselves, being much closer to each other than the three electric lights, the lenses were brought much nearer to each other, and instead of the wide spaces of four feet as between the electric lenses, the fixed gaslight lenses were not separated by more than half a foot, and the revolving lenses were practically joined together, forming a continuous mass of glass nearly 17 feet high.

In lantern C three segments of a lenticular belt, similar in all respects to those in the gas lantern, were mounted for the fixed light, but owing to the great distance apart of the oil burners, the lenses were separated by distances of three feet, which naturally told against the pillar of oil light in comparison with that of four compactly fitted gas burners, shining through four lenses practically not separated. In the revolving light an endeavor was made to compensate for this defect by the use of lenses of larger vertical section, such as are employed at the Eddystone. With these larger lenses, made by Chance Bros., of Birmingham, the outer rings were of flint glass, which has a higher refractory index. The horizontal dimension and the focal distance of these lenses were the same as those in the gas tower. The height only was different, it being apparently sought to

make up by lens-power or lens-area, for the want of a fourth light.

This completes the three divisions I ventured to make at the commencement of my paper, and it will be evident to all that very careful and elaborate arrangements with the aid of burners and lenses have been made in each case to get the most out of each illuminant, and to exemplify each lighting system effectively at South Foreland. But the value of a lighthouse illuminant is not reckoned solely by the brightness with which it shines through the darkness of night. For clear weather the lights of ordinary power were and are sufficient for the use of the mariner, provided a sufficient individuality be given to each by which it can be readily recognised. The whole purpose of developing these larger and more powerful lights is to overcome the resistance offered to the passage of light rays through the atmosphere, by the obstructing medium of watery vapor in its various gradations from thin haze to thick fog. The times have long gone by when merchant ships would anchor if even a small fog appeared; now-a-days maritime traffic round our coasts stops for nothing. Sound fog signals have become a necessity of the times, to be sounded so soon as the effectiveness of lights is seriously impaired by a thickened atmosphere. But it is very desirable that the lights should hold out as long as possible; that though the effect of a haze might be to lessen the range of a light, yet that its rays should penetrate sufficiently through the haze to be of some practical service to the mariner, to be seen by him in time to prevent his running into danger, or to guide him on his way. If any one illuminant is proved to be able to cope more successfully than the others with this obstructing medium, that light can certainly claim to be supe rior for lighthouse purposes in thick weather. This, then, is the great problem which is to be solved; which of the three systems, oil, gas, or electricity, when exhibited under the most favorable conditions, has the greatest penetrative power in thick weather? And in connection with the solution of this problem it will be found that considerations of economy and convenience cannot be dissociated from the question.

It will, doubtless, be evident that the question of the relative merits of lighthouse illuminants is considerably more complicated than the general public think it is. We have seen what is the nature of the competitive illuminants, and how they are dependent on burners and lenses to make them serviceable for lighthouse purposes; also how they were exemplified in A B and C towers at South Foreland. We are, therefore, better prepared to enter upon the direct consideration of the actual trials.

A few words may here be interpolated regarding the personal arrangements for carrying out the experiments.

Upon the dissolution of the Illuminants Committee, for reasons which need not be discussed here, this tangled question was by the Board of Trade referred to the Corporation of Trinity-house, who accepted the responsibility of carrying out the investigation, seeing that a great deal of public interest had been drawn to the question. A Committee was formed of members of the Corporation, consisting of Captain Sydney Webb, the deputy-master, as chairman; Captain Nisbet, Captain Weller, Captain E. A. Vyvyan, Captain Burne, Admiral Sir Leopold McClintock, and Mr. John Inglis, secretary to the corporation; to this committee I had the honor of being appointed secretary. The first thing done was to obtain the friendly co-operation of the Scotch and Irish Lighthouse Boards, and it is only proper to state that such co-operation was most cordially extended by both Boards and their officers to the Trinity-house Committee. The Committee had the great advantage of frequent personal communication with Mr. Thomas Stevenson, the eminent engineer to the Scotch Lighthouse Commissioners, and with Sir Robert Ball, the Astronomer-Royal of Ireland, and Scientific Adviser to the Commissioners of Irish Lights. They also invited, and were fortunate enough to secure, the aid of Professor W. Grylls Adams, F.R.S., of King's College, London, and Mr Harold Dixon, of Balliol College, Oxford, the former for advice and assistance in respect of the electric lighting apparatus, the latter for aid in carrying out the necessary photometric observations on the various lights to be exhibited. In addition they had the great advantage of frequent consultations with Mr. Vernon Harcourt, F.R.S., of Trinity

College, Oxford, who watched the trials on behalf of the Board of Trade, and whose knowledge of photometric work is probably unequalled in this country; further, the invaluable practical experience and profound knowledge of lighthouse experiments of Sir James Douglass were at all times available, and the suggestions and opinions of representatives of foreign lighthouse authorities were cordially given and received.

It was in full view of all the world, and specially all who were in any way interested in the subject, that the experiments were commenced and carried through; the whole arrangements were open to the fullest and freest public inspection. It is essential to make it quite clear that the Trinity house Committee courted inquiry, suggestion, and inspection. They only desired to arrive at a just decision; and I, as secretary to that Committee, and with all respect to those who may have been inclined to think otherwise, venture to challenge anyone to prove the contrary.

The South Foreland station was selected for the trials because of the existing facilities for observations on land and at sea, and because there was a sufficient reserve of steam power, over and above that required for the machines feeding the permanent lights, to operate the additional electric machines. The land in the neighborhood of South Foreland is undulating, but has no hedges and few trees, and therefore affords facilities for observing the lights at distances of between two and three miles.

It may be assumed that the three lighting systems were adequately represented by the apparatus set up at South Foreland; the arrangements for exemplifying the electric and oil systems in A and C towers, were made under the immediate direction of the Trinity-house Committee and their engineer, Sir James Douglass. The exemplification of the gas system was left in the hands of Mr. Wigham to arrange, as he thought best, for the exhibition of his quadriform light. It is true that the Committee demurred to making trial of what Mr. Wigham called his double quadriform, *i.e.*, two sets of four lights placed side by side in the lantern, which he urged upon them, they not having any practical experience of the effect of burning eight large gas flames in a lighthouse lantern for several hours, nor could they learn that the Commissioners of Irish Lights had had any such experience. With this limitation only, Mr. Wigham had perfect liberty to show the best light he could produce with four large burners p'aced vertically his foreman, Mr. Higginbotham, might use as much or as little gas as he thought proper; he might regulate his draught as he liked; he had the gas manufacture under his own supervision, and made as much, or as little as, and of what quality, he pleased; the cannel coal was specially selected by Mr. Wigham, and no restriction of any kind was placed upon his foreman as to the mode of keeping up his light. He was simply required by the Committee to show a certain light at a certain time, in order that it might be compared with another light, and it was entirely his own business how he produced that light. He was not controled in any way whatever, and I can testify that it was through no default on the part of Mr. Higginbotham that the gas light did not outshine the most powerful electric beam. Mr. Higginbotham's mechanical ingenuity always being applied to improve the gas-light, and his devoted loyalty to the interests of his employers, were noticeable points in connection with the gas-light exhibition. A Trinity-house lightkeeper was on duty in this lantern, but he had no power to interfere with Mr. Higginbotham's management of the light. It should also be mentioned that the electric and oil towers were manned by Trinity-house keepers, over whom, as well as over the whole experimental establishment, Mr. J. Sparling, the very intelligent engineer in charge of the South Foreland permanent station, exercised a general supervision, subject to the members of the Committee, who it was arranged should be constantly on the spot.

OBSERVATIONS.

Assuming all the necessary arrangements to have been made for exhibiting the various lights at the South Foreland, the next matter for consideration is how they were observed. It was resolved that two kinds of evidence should be obtained in reference to the relative merits of the illuminants, as shown, the one of a practical nature from competent eye witnesses at various distances, the other of a more

scientific or expert character. With regard to the former, it may be stated that from the lightsmen on board the Gull, the Goodwin, and the Varne light-ships; the pilots and masters of vessels navigating in the vicinity; the Elder Brethren of Trinity-house and their officers; the coastguardsmen between the South and North Forelands; valuable data were obtained respecting the relative merits of the lights in different kinds of weather, and at various distances, from one to twenty-four miles. In addition to the observations so made at sea and on land, special watchmen were detailed to observe the lights nightly at shorter distances, along a line marked off by posts 100 feet apart, and running across the country for a total distance of two and a-half miles, all the competing lights being fully visible in clear weather along the whole length of this line. Three huts were set up along this line—No. 1 at a distance of 2,144 feet, or nearly half a mile from the lights; No. 2, 6,200 feet, or nearly one and a quarter mile, and No. 3 at the extreme point, two and half miles. The night walks along the lines, the blinding effect of the lights, and the welcome shelter in the huts, will, doubtless, be remembered with interest by many of the visitors who joined the observing parties. This short range was very serviceable on nights when haze or fog prevailed, it being possible to measure with a very fair approximation to accuracy the distance at which each light was observed. The observations made were recorded in books specially prepared for the purpose, on a uniform system; thus all the returns were made in the same way. The instructions were as follows:

INSTRUCTIONS TO OBSERVERS.

The lights to be observed will be shown from three towers in a line bearing N.W. from the permanent high lighthouse, and will be identified by means of the letters A, B, and C respectively.

When possible, observations of the three lights should be made at each hour from 8 P.M. to midnight.

In recording an observation, put down in the A column the light from the A tower as 100, and in the corresponding B or C column put down the number as compared with 100, which represents the difference in power. Thus, if B appears to be twice as good as A, and C appears to be only half as good as A, the record should be A 100, B 200, C 50. In the columns headed "Place of Observation," it is requested that the position and distance from South Foreland may be stated as accurately as possible at every observation recorded.

The state of the atmosphere each night is to be carefully noted, and recorded in the column provided for the purpose, in one or more of the following terms: Clear; cloudy; very dark; moonlight; hazy; slight fog; ordinary fog; drizzling rain; ordinary rain; heavy rain; snow; hail; sleet. Each night's record to be signed by the observer, the place of observation being in every case clearly indicated.

Remarks of a special nature concerning the appearance of the lights are to be made on the fly-leaf provided for the purpose. Under this heading observers should record any apparent difference in the color; any apparent unsteadiness, variations, or obscurations of the lights; also the effect of the lights upon the clouds: and, where a fair comparison is possible, of the relative value of other lights in the vicinity, those on the French coast, for example.

The other kind of evidence sought to be obtained was that of the scientific measurement of lights by the most approved photometrical methods. These operations were carried on at the three huts before mentioned, and in a dark gallery 380 feet long, specially constructed for the measurement of large and powerful lights. This portion of the investigation was mainly in the hands of Mr. Harold Dixon, who had the advantage of frequent communication with Mr. Vernon Harcourt on the subject, and able assistance in carrying out his work from Sir James Douglass, Messrs. Lyle and Longford (who at Dr. Ball's suggestion were sent to South Foreland as the representatives of the Irish Lighthouse Board), and Mr. Sparling. All the various lights exhibited were subjected to measurement, both as naked flames and as shown through lenses, the value of each being expressed in numbers of candles. For these measurements the Harcourt pentane standard flame, adjusted to correspond with accuracy to the average flame of a number of sperm candles, was chiefly

emp'oyed; but occasionally a portion of the flame of a mineral oil Douglass burner, enclosed in a square iron-sided lantern, was used. A small opening in one side of this lantern was fitted with a Methven screen, so adjustable that the rays passing through the opening would represent $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, 4, or other convenient candle-power, as might be desired, in accordance with the single flame of the pentane standard. A portable pentane lamp was generally used in the huts, but on windy nights the Douglass flame was found to be very serviceable, being less sensitive than the unprotected pentane flame. In the photometric gallery, a standard pentane flame in connection with a complete apparatus for making the gas on a sufficiently large scale was available. Without going into detail respecting the manufacture of the gas and the special merits of the pentane standard of light, I may here record the fact that with its aid a great deal of valuable and trustworthy work was done.

Although I do not propose to enter upon a detailed consideration of the photometric methods employed by Mr. Harold Dixon and Mr. Vernon Harcourt, the subject being one which could not be adequately discussed in the space of time at my disposal, yet some remarks of a general character may be made upon the subject.

Let me first say, for the benefit of those to whom photometry is a dark study, that the standard light is that in comparison with which the light under test is to be measured. The value of this standard light is expressed in candle-power.

At South Foreland the naked lights were measured in the photometric gallery, and the lights through lenses at No. 1 or No. 2 hut. The principle mostly adopted with the former was to cause the light of the standard flame to fall on one side, and that of the light under measurement upon the other side of a movable screen with a translucent star disc in the centre. By moving the screen to and fro along the graduated bar, a position could be found where the stars would show with equal distinctness on both sides of the screen. In such circumstances, the illuminating power of the burner under measurement would be directly as the squares of the distances between the disc and the burner, and between the disc and the standard light.

A modification of this method was occasionally employed in the gallery, and always at No. 1 hut, distant 2,150 feet from the lights. The light of the standard flame, and that of the illuminant under test, were thrown upon the same side of a disc of translucent paper fixed in the centre of an opaque screen, while, by means of an umbrant or shadow-thrower, contiguous portions of the disc were illuminated by the standard and the distant light. By moving the table nearer to or distant from the standard, a position was found where the illumination in the three divisions of the disc appeared to be equal. By this method direct measurements of all the lights in A, B, and C towers could be made at No. 1 hut.

At hut 2 the bar photometer with the movable star disc was used, but owing to the great distance from A, B, and C lights, 6,200 feet, it was found necessary to condense the light from the distant towers by a small achromatic lens interposed in the path of the beam entering through a circular opening in the window screen. In thus condensing the light, a certain loss by absorption and reflection was experienced, but in all measurements the requisite correction on this account was applied.

In this connection it was feared that the difference of color between the light of the electric arc and that of the standard flame would be a serious difficulty, and would prevent an effectual comparison being made as to relative illuminating power of the different colored lights. But Mr. Dixon says "that with the use of the star disc no such difficulty was felt. Equality of distinctness in the pattern of the star on both sides of the disc could be judged without difficulty, although both star and back ground appeared of complementary tints on the two sides. Since the object of the investigation was to determine for each illuminant the total quantity of light which affected the eye and conferred visibility upon the lamp, independently of its color, the distinctness of a pattern, illuminated by lights of different color, seemed to afford a criterion of their true illuminating power less open to error than any method of striking an average between the illuminating power of separate groups of

colored rays filtered from each beam by the interposition of colored media. It was also found that different observers made concordant measurements of the electric light with the star disc."

The lights were exhibited, watched by many observers, and measured by the indefatigable photometrists over a period of twelve months. During that period a large amount of valuable evidence was collected, by the aid of which the committee were subsequently enabled to state their conclusions with definiteness.

RESULTS.

At a comparatively early stage of the trials it was found that no practical advantage was gained by superposing electric lights, but that, for the reasons previously stated, a sufficiently effective result was obtained from one arc fed by two electric machines. This form of light was accepted by the Committee as that best suited for the exposition of the electric system, and that upon which it should be judged in respect of its merits as a lighthouse illuminant.

For gas, the columnar light of the quadriform arrangement, with a burner of 108 jets for each tier, was the highest power available, and was regarded as the best representative of the gas system.

For oil, the Committee had resolved to rely upon the performance of the 6-wick burners, which had been in use in the Trinity-house service for many years; and three of these, mounted in triform arrangement, as has been described, were adopted by the Committee as representing the best effect which could then be produced with the oil system.

It will be plain that for the large flame lights there was ample recognition of the value of the system of superposing, a recognition, doubtless, very gratifying to Mr. Wigham, who successfully developed the system with his gas apparatus, although others may have tentatively preceded him in the same direction. It was certainly proved by the trials that the system possesses some real advantages. But it is very essential that provisions be made to check the radiation of heat from the flue pipes. With the superposed oil burners effectual measures were adopted, but not in the case of gas, consequently with the four great gas lights burning in a lighthouse lantern, the heat generated would be so considerable as to endanger the safety of the lenses, and render the lantern uninhabitable. Mr. Higginbotham, Mr. Wigham's foreman, bore the heat in the gas lantern at South Foreland like a genuine salamander; but there are some lighthouse keepers who would be likely to frizzle and grill under such conditions. I may mention that the temperatures in the lantern, when the four burners were alight, ranged from 180° F, in the lowest tier, to 370 F. in the highest. It was this great heat, taken in conjunction with the cracking of some of the lenses, which influenced the Committee in declining to try Mr. Wigham's double quadriform light, in which eight instead of four burners were to be burned in the lantern. If four burners made the temperature 370°, what would eight burners have done?

A great number of experiments were of course made with the lower powers of the respective illuminants, and information gained which will be of very great value in the lighthouse service; but in stating the results of the trials, it will be sufficient to regard each light as shown at its highest power, viz.: Electric, one light, two machines; gas, four lights, 108 jets; oil, three lights, six wicks.

Clear Weather.—In fine weather it was evident that all the lights were too good, and that for merely sending an effective beam of light to the horizon on a dark clear night, no one was really better than another, although it may be said that the experimental electric light was regarded as a nuisance rather than otherwise by mariners in the near neighborhood of the South Foreland. It is quite certain that for clear weather the lower powers of any one of the illuminants would be sufficiently serviceable for the requirements of the mariner, either as a fixed or a revolving light. This is proved by the reports made by distant observers, who, on a clear night, would record that the single lights were not less effective than the triform or quadriform arrangement. In this connection, *i.e.*, as regards clear weather, the only points really noticeable are in respect of the adaptability of the lights for occultations, one of the distinctive characteristics used for lighthouse lights, and for marking special dangers by means of colored sectors. As regards occultations, it is clear that, although with the

electric light a simple arrangement might be devised of breaking contact and renewing it at certain periodic intervals, it would not be accomplished without some risk to the steadiness of the light, and, moreover, would not be worth while, because the generation of electricity would still be going on, and nothing would be saved. In the case of oil, it is not very easy to turn the light up and down to produce the effect of occultation. It it were, some saving in oil consumption might perhaps be gained, but it would be very small. To produce occultation with electric and oil lights it is therefore necessary to employ a simple mechanism, by which a cylindrical screen falls and eclipses the light for the requisite period, and is then drawn up. But with gas, the turning off and on of the supply is sufficient to produce occultation in an economical and effective manner. This is certainly a point to the credit of the gas system, but its effective application is limited to fixed lights, for it is questionable whether this kind of occultation can be applied with success to flashing or revolving lights.

For colored sectors it is necessary that the limiting radii should be as sharply defined as possible, that mariners may know immediately they go over the border line. With large flame lights, the border lines are not clearly defined, but instead are found areas of uncertain light of varying width. With the electric light this width is only a few feet at a distance of 1¼ mile; with the gas light at full power it is over 140 feet at the same distance; and with the oil light at full power it appears to be between 50 and 60 feet. The changing of the points of incandescence in the carbons causes the electric light line to move within a range of 15 feet, but the line of definition is always sharp. The width of the uncertain light increases in proportion to the distance, and it is consequently of importance to obtain the sharpest possible definition of the sector. Electric, for this is certainly the best, the oil system, with 6-wick burners, being a good deal better than the gas system with great 108-jet burners.

Haze and Fog.—We now come to the question of haze and fog.

The gradations of atmospheric transparency are numerous, and it is between such extremes that the mariner finds powerful lights specially useful. It is when the atmospheric transparency is impaired more or less that these strong lights are required. It is very difficult to graduate the opacity of the atmosphere, but for our purpose it will be convenient to separate weather which in a general way is misty or hazy from that which is essentially foggy.

The general result of all the observations made in respect of haze, show incontestably that the single electric light, as shown from the A tower, greatly excels the most powerful superposed gas or oil light in penetrating power, either as a fixed or revolving light. Of 284 eye observations recorded as made in weather not clear, but without actual fog, the mean percentage of superiority of the electric light over gas is about 36, and over oil, 41. These percentages must not be taken literally, they are not intended to convey exact numerical ratios, but are founded upon the estimates of many and various observers at different positions, and possibly under different conditions. But the general verdict of superiority of the electric light in such conditions of weather is plain and unmistakable. It is always better than anything else.

As regards gas and oil, 231 observations of quadriform gas, 108 jets revolving, as compared with triform oil 6 wicks revolving, made at times when the transparency of the atmosphere was impaired by mist, haze, rain, or snow, show that the gas light has a mean percentage of superiority 5.8 per cent. When shown as fixed lights, the superiority of gas over oil is increased to 12.2 per cent. as the mean of 72 observations. In this case the body of miscellaneous observers give their verdict that the gas light is better than the oil light. This advantage does not mean that the revolving gas light penetrates to a greater distance than the revolving oil light, but merely that at the points of observation, near or far, where both are seen, the gas light is regarded as better than the oil light. But, for all practical purposes, the oil light is seen whenever the gas light is seen, although it is evident that the gas is the better light of the two, as it ought to be with its four lights against three. As a fixed light, the gas certainly has the best of the oil. The four closely packed 108-jet gas flames showing

through their closely-fitted lenses, yield a column of light very superior to that of the three widely separated 6-wick oil lights. As exemplified at South Foreland, the oil light was beaten by the fixed gas light. But without stopping to inquire whether a better effect could have been made with the fixed oil light it may be said that fixed lights are gradually becoming of less importance, owing to the necessity for providing lights with distinctive characteristics, for condensing the rays into strong beams, and to avoid lighthouse lights being mistaken for anchor or other lights on board vessels at sea.

In actual fog the electric again holds its own. The experience of fogs at South Foreland, though not large, was sufficient to furnish valuable comparisons, and it was proved beyond question that the single electric light pierced a greater depth of fog than the highest powers of either gas or oil. The quadriform gas and triform oil lights were practically equal in fog, though some observers occasionally recorded the gas as a few feet better. But in such fogs the mariner would not derive the slightest advantage from any light. The recorded distance to which lights were carried, or where they were picked up in the fog, range mostly between 700 and 2,000 feet from the lights themselves, and the superiority of the electric light is determined by its penetrating 200 or 300 feet further than the gas or oil lights. The most powerful electric light was shut out on one occasion at 1,450 feet, on another at 1,500, another at 1,700, on another at 1,500, another at 1,300 feet. It will be plain to all here that no mariner could possibly be benefited by a light which was not visible at such distances from the lighthouse. And for purposes of navigation a difference in the visibility of the lights of 200 or 300 feet is of no value whatever. One remarkable fact stands out prominently here, viz., the greater ratio of absorption by the fog of the electric rays as compared with the gas and oil rays. Fortunately for the electric light, as shown at South Foreland, it possessed a large reserve of initial intensity, which enabled it, notwithstanding its much greater proportion of loss by absorption of its more refrangible rays, to penetrate further than the other illuminants. With three lights of equal candle power, one electric, one gas, one oil, exhibited in a foggy atmosphere, there is little doubt that the electric would be eclipsed at a much shorter distance than the others; but as the electric beam can be made so much more intense than it is possible to make the gas or oil beam, the electric light, though heavily handicapped, beat its competitors in fog by the superabundance of its own luminous energy.

Such, then, are the results obtained from the testimony of eye witnesses. The photometric measurements entirely corroborate the eye observations as to the superiority of the electric light in all weathers, both in revolving and fixed phase. They also give the 108-jet gas burner a superiority over the 6-wick oil burner, when both were shown through similar lenses; and, taking the mean of all weathers, the former is credited with an advantage of 16 per cent. over the latter. But it is important to note Mr. Harold Dixon's remarks on this point. He says "this difference in illuminating power means but slight difference in penetrating power. In many observations, both on sea and land, in haze and in thick fog, the quadriform 108-jet gas light was picked up just before, but only just before, the triform 6-wick oil light; in other observations the two lights were picked up simultaneously." This exactly coincides with the evidence of the eye witnesses, and supports the belief that the four lights in the gas lantern just managed to hold their own and no more against the three lights in the oil lantern.

The table in page 505 gives the value of all the burners in clear weather. The results are stated for a single burner in each case, but to obtain the value of quadriform gas or triform oil it is only necessary to muliply by four or three.

The experiments have shown clearly that, light for light, *i.e.* diameter for diameter, gas and oil are very much alike in illuminating power; indeed, under such conditions, the oil flame seems to be rather the better. They have also shown that oil lights can be superposed with the same facility as gas lights, and can be exhibited under similar conditions, with one exception, that no oil flame has yet been brought to the enormous size of the 108-jet burner. But as this enormous size of flame is not required, this

TABLE OF PHOTOMETRIC VALUES.

Name of burner.	Dimensions of the flame.			Illuminating power in candles (mean results).			
					Through lenses in clear weather		
	On the burner.	At focal plane.	Height.	Naked flames.	Cylindr. belt.	Eddystone.	Mew Island.
	Inches.	Inches.	Inches.		Fixed light.	Revolving light.	Revolv. light.
6-wick oil, Douglass, old pattern	4¾	4⅜	5	730	5,000	64,000	48,000
7-wick oil, Douglass, new pattern	5⅞	4⅜	6	947	8,100	60,000	49,000
8-wick oil, Douglass, new pattern	7½	5⅛	6½	1,400	..	..	..
9-wick oil, Douglass, new pattern	7½	5⅛	6½	1,785	..	..	..
6-ring gas, Douglass (cannel)	4⅜	2⅞	5	825	6,700	92,000	70,000
10-ring gas, Douglass (cannel)	7½	5⅛	6½	2,500	12,899	105,000	94,000
108-jet gas, Wigham (cannel)	11¼	11¼	13*	2,300	15,600	..	59,000
88-jet gas, Wigham (cannel)	9½	9½	13*	1,400	13,000	..	54,000
68-jet gas, " "	7⅜	7⅜	13*	980	8,800	..	48,000
48-jet gas, " "	6	6	12*	689	5,700	..	42,000
28-jet gas, " "	4¼	4¼	12*	250	3,000	..	33,000
Regenerative gas, Siemens (cannel)	10	10	6	600	3,300	10,000	..
Regenerative gas, Siemens, small size (cannel)	4	4	4	194	..	..	..
6-ring gas, Sugg (cannel)	7½	7½	8½	824	5,600	55,000	..
						Cylindr. belt with vertical prisms. revolv. light.	
Electric, 1 machine	..	..	..	10,000	120,000	1,250,000	..
Electric, 2 machine	..	..	..	15,000	150,000	1,500,000	..

* 4½ to 5 inches of these heights are naked flames, the remainder is surrounded by a transparent talc chimney.

is not of great consequence. As the two lights were shown to be so nearly equal, the questions of convenience and economy assumed very considerable importance in connection with their relative merits as lighthouse illuminants. It had to be considered that the gas system could not be taken to a rock lighthouse or used on board a light vessel, therefore its application would have to be limited to lighthouses on the mainland. The necessity for the erection of gasworks, gas-holders, mains and pipes, &c., involved a large expense, all of which might be justifiable if the advantage to be gained were proportionate. But, on the other hand, mineral oil was found to be so cheap, so easily supplied and stored, and so easily managed, that the balance of advantage was seen to be distinctly in its favor. Here is the real enemy which has beaten the gas system. As I before observed, the arguments employed in the early part of this discussion to demonstrate the economy of the gas system were based on the then prices of rape seed oil at 4s. 9½d., 3s. 10½d., 2s. 9d. per gallon, but times are changed; mineral oil has now replaced the high priced rape seed oil, and is supplied at 6d. per gallon. It is this fact which has demolished all elaborate computations to prove the

economy of gas. Notwithstanding Mr. Wigham's great ingenuity and perseverance, circumstances over which he has no control have vanquished him; and if at any time Mr. Wigham can bring down the price of coal gas so that the light is less costly than that of mineral oil, he may reasonably expect that oil will then have to take a back seat. But that time is not yet.

The whole result may be approximately stated as follows:—For expenditure of raw material only, without reference to plant, labor, &c., a 6-wick mineral oil lamp burning for six hours would consume four gallons of oil at 6d.=2s., or, say, 3s., including wicks, cylinders, &c. A 108-jet burner alight for the same period would consume 1,800 cubic feet of gas, at a cost of not less than 10s. for coal alone. Taking all these considerations into account, it will not be surprising to this audience to hear that the final conclusion of the committee was:

"That for ordinary necessities of light-house illumination, mineral oil is the most suitable and economical illuminant, and that for salient headlands, important landfalls, and places where a very powerful light is required, electricity offers the greatest advantages."

DISCUSSION.

The Chairman, in opening the discussion, pointed out the thorough manner in which the testing of the lights in the experiments spoken of had been carried out over long intervals of time, and under a variety of circumstances. No doubt, therefore, could attach to the conclusions arrived at. From a practical point of view, one of the most interesting results was the short distance penetrated by the most powerful lights, and it seemed that a doubling or trebling of the lights in many cases very little increased their power of penetration through fog. Perhaps, after all, that was what might have been expected, for when powerful lights of many thousand candles were entirely quenched at the distance of a few thousand feet, it was evident that in every few hundred feet of that distance the lights must be diminished in considerable proportion. Further particulars as to the less penetrating power of the electric light as compared with oil or gas would be interesting. To a certain extent people were misled by ordinary London experience of fogs. It was a matter of common observation in London, a few years ago, when the electric lights were burning on the embankment, that at a very moderate distance they seemed to be almost as red as the gas lights burning beside them, but that effect was more likely to be produced by the London smoke rather than by what could be properly called fog. When the sun at midday is shining through a bank of cloud which allows its line to be visible, it is seen, not altered in color, but in its original whiteness. At sunset, it was true, when the sun shines through a lower stratum of the atmosphere, a red color is perceptible, but that appearance could not properly be attributed to fog or cloud, otherwise the same effect would be observed when the sun was high in the heavens, and its rays had to pass through a mile or a mile and a half of cloud. A little more than a year ago he had himself witnessed the experiments with these lights, and had spent a very interesting night walking between the huts spoken of, placed at various distances from them, and in observing the effects of the lights, and the careful arrangements made with reference to photometry. As to the comparison of the effect of lights of different colors, he saw the star-disk arrangement spoken of in the paper, and had verified the possibility of taking very accurate observations in spite of difference in color between the electric and gas and oil lights. Within the last week Captain Abney and General Festing had brought before the Royal Society a very interesting account of some elaborate observations which had been made upon this very subject of the photometry of different colored lights, and they had proved (rather to the surprise of many) that it was possible to make comparisons between lights of very various colors, between white light and the green, or red lights and the spectrum, almost as accurately (Captain Abney said, within 1 or 2 per cent.) as could be done between lights of absolutely the same color. In estimating the rapidity of the alternation of the currents, Mr. Edwards appeared to have multiplied the number of coils by the number of revolutions, assuming that each coil sent a distinct pulse. He thought the arrangement was such that

each passage of the coils in front of the magnet page one pulse, so that the number of coils should not be multiplied by the number of revolutions to obtain the number of pulses. He scarcely thought that the number of pulses could be so many as over a million in a minute, as had been stated, but some of the gentlemen present would probably be able to speak upon that point.

Professor W. G. Adams, F.R.S., said that, from his own personal observations and measurements, he could bear Mr. Edwards out in many of the remarks which he had made with regard to the relative illuminating powers of gas and oil, and of the electric light, under the arrangements for their comparison which were made at the South Foreland. As regards the comparison of oil and gas, he thought Mr. Edwards had given a full and fair account of their relative merits, and had drawn just conclusions on them. He would strongly emphasize the praise of the Douglass 6 and 10-ring gas-burners, for he felt sure that all who had the opportunity of judging must be of opinion that for the compactness of the burner, the concentration and steadiness of the flame, and for the remarkable economy of gas, these Douglass gas-burners far surpassed any other gas burner which had ever been tried for lighthouse work. The 6-ring burner, 4½ inches in diameter, gives the light of 108-jet gas, 11¼ inches in diameter, and only consumes one-third of the amount of gas consumed by the 108-jet burner. The 10-ring Douglass gas-burner, 7½ inches in diameter, gives 60 per cent. better light, and only consumes two-thirds of the gas of the Wigham 108-jet burner. The relative smallness of these flames is of great importance in their use behind a lighthouse lens. And here he would draw attention to a fallacy which seemed to exist in certain quarters, and from which Mr. Edwards did not seem to be quite free, but which had been fully proved to be a fallacy by the experiments at the South Foreland. It is assumed that a second order lens, or even a third or a fourth order lens, is quite large enough for a source of light of small size like the electric light. The results, as given by Mr. Edwards, have shown that if the object was to prove the superiority of the electric light over any other light for lighthouse use, then the second order lens was quite sufficient to show this superiority under any conditions of weather. As long as oil and gas flames were of moderate size, say four inches in diameter, second order lenses did fairly well; but when flames 6 or 8 inches in diameter came into use, there was found to be little or nor increase in the light, and so the lenses too must grow, and we must have Fresnel's first order lenses. Then, again, the flame grows to 10 or 11 inches, and even first order lenses give very little increase over smaller flames, as shown by comparison of Wigham 88-jet and 100-jet gas in Mr. Edwards' table; and so it becomes necessary to construct a lens, as Mr. Stevenson has done, which considerably exceeds in size what has hitherto been called "the first order lens." The experiments at the South Foreland have shown, and Mr. Edwards' table proves it, that lights concentrated into a smaller focus, and especially electric lights, gain more than any others by the use of larger lenses. Compare the Douglass 6-wick oil (730 candles), the Wigham 68 jet gas (990), and the Douglass 6-ring gas (825), when used behind the same Mew Island lens. Much more is this the case with the electric light. Had Mr. Edwards completed his table, and given the illuminating power of the electric light through the Mew Island lens, as given in his (Professor Adams') report, the numbers, 15,000,000 and 18,000,000, would have been seen in the last columns of that table as compared with 59,000 for the 108-jet gas. The multiplying power of the lens for the electric light would have been 1,500, whereas for the 108-jet gas it is only 25, and about 38 for the Douglass 10-ring gas. It will be seen that, with the cylindrical belt with vertical prisms, the multiplying power for electric light is 125, and for the Mew Island lens it is twelve times as great, or 1,500. For the adequate comparisons of the electric light with other systems of lighthouse lighting, it is essential that the same lenses should be used, and for this as well as for some other reasons, we must look upon the results of the South Foreland experiments as only showing that the electric light is superior to every other light, but not by any means as showing what the electric light is capable of doing. His (Professor Adams's) report showed that

much more has been done, and that under favorable conditions far more of the electric energy can be converted into light-giving rays. The merits of the electric light as a lighthouse illuminant cannot, as his report showed, be arrived at simply by the results as shown from the A tower at the South Foreland, without taking into account the loss of energy to which Mr. Edwards had alluded, and which would not exist in any permanent installation. With regard to these experiments, he (Professor Adams) had been asked by practical men how it is that so little light as 10,000 or 12,000 candles is obtained from the expenditure of so much energy, when we get more efficiency and far more effective work from our dynamo machines. To some extent this is true, and may easily be accounted for. A machine does most effective work when the external resistance of the circuit is not greater than the internal resistance of the machine; now in this case the internal resistance of the De Meritens machine is .05 ohms, and the resistance of the leading wires to the tower (to say nothing of the lamp and the electric arc) is .077 ohms, or more than half as much again. Hence it will be evident to all practical men that these excellent De Meritens machines can do far more than has hitherto been done with them. Whereas the light in the A tower is given by a current of 100 amperes, or at most 130 amperes, the machine has given a current of 420 amperes when the electric lamp was not far away from the De Meritens machine. With regard to the apology of Mr. Edwards, or the reason he alleges why the electric light has not been used in England, although it has been received more favorably in France (on the French coast there are 42 electric lights), he would ask if the mariners ever object to the dazzling brightness of the sun, and if the electric light does not more nearly resemble brilliant moonlight? Mr. Edwards said the electric light was removed from Dungeness, because mariners disliked it, but he (Professor Adams) had shown in his lecture at Aberdeen, before the British Association, what mariners thought of the electric light of the South Foreland when it was first established there; he quoted from a work of M. Petit, translated by Mr. Edwards. M. Petit says: "The advantages of the system have been highly appreciated by mariners, and the increase of range of the lights has been very marked in slightly foggy weather. It certainly enables mariners to continue their voyage, and to enter a port at night, when they would not have been able to do so with oil lights." M. Petit for many years was commander of a steamer on the postal service from Ostend to Dover. To M. Petit's paper, and to his (Professor Adams) report to the Trinity House, as well as to his lecture at Aberdeen, he must refer for proof that the step from oil lights of 1870 to electric light of 1884 represents an improvement in the proportion of from 30 per cent. to 90 per cent. in lighthouse illumination, and that the number of nights on which the electric light is seen 20 miles away is about 90 in every 100. On a few very thick nights an increase of 100-fold in the source of light, whether it be electricity, gas, or oil, will hardly increase the distance to which the light is seen by 100 yards. He thought Mr. Edwards must have made a mistake in his description of the mode of coupling the machines. The two machines coupled parallel have an E.M.F. of 60 volts, and a current of 176 amperes, and the two machines in series are said to be also of 60 volts, and a current very nearly the same; these values seem to show that in this case the coupling must have been also parallel, probably the opposite poles of the magneto machines were connected. He was glad to hear of Mr. Edwards state that the electric light can generally be maintained with a fair amount of steadiness, and that the fluctuations have not been very serious, but I think no friend to electric lighting can ever hold with him that its unsteadiness may be advantageous. As regards the size of lenses used in the A tower, they extended only over 30° of arc, bringing the bundle of rays into a parallel beam, whereas the Mew Island lenses in the B tower extended over 60° of arc, both horizontally and vertically. With regard to the greater absorption of the electric beam by the atmosphere, the experiments with steam fogs had shown that it was by no means so great as was previously supposed. The illumination given by the blue and violet rays is very small, and even if they were absorbed, the total light would not be thereby very

much reduced. The experiments at the South Foreland have shown that, using the large Mew Island lens, with the 10-jet gas of 2,400 candles, and the electric light of 12,000 candles with the smaller lens, the electric light in clear weather was at least sixteen times as bright, and in foggy weather was about thirteen times as bright as the gas light, the excess of absorption for the electric light being about 20 per cent. more in foggy than in clear weather. Had the same lenses been used for both electric light and gas, the illumination given by the electric light would have been from 150 to 200 times the light from gas.

Professor C. Vernon Harcourt, F.R.S., said one of the points of most general importance was that raised by the Chairman as to the relative absorption of the electric and of other lights by the atmosphere in a certain condition. It might be that one of the causes why the electric light was credited with suffering more by atmospheric absorption was that so many observations were made in London, and that London fog differed perceptibly from such haze and mist as was met with at sea; and it might differ in respect of possessing this selective absorption in much greater degree than when the air was simply obscured by suspended particles of water. When there was rain falling, or there was a wet fog, such as was met with sometimes on ascending a mountain, the obstruction to the light was suffered equally by light of all degrees of refrangibility, and it might be that when the water was more finely divided, as in a haze, that this selective absorption occurred where the size of the globules was comparable with the wave-length. He was glad to hear Professor Adams' remarks as to the degree to which absorption reached. Becquerel stated that for solar light the rays from blue to violet were 14 per cent. of the whole; but it had been stated that the proportion of these rays was greater in the electric light than in the solar light; and perhaps in that case the total absorbed in this selective way might be more than 14 per cent. It was very important to have some such limit fixed to the possible loss of light in this way. It was also important to understand that the way in which the atmospheric absorption acted was, as Professor Adams had described, that each stratum of thick air which the light passed through, cut off a certain fraction, and that the same abstraction happened to all light of the same color, and was of such a character that there might be a great disproportion between the increase which might be produced in the light and the cone of rays which was the consequence of that increase. If the fog were such that one of Mr. Wigham's single lights were extinguished at two miles, the quadriform light would only extend to 2.1 miles, or something like that. Sometimes expressions were used as if it were possible to produce light of such a kind that it would go clean through a fog, but that was quite impossible. It was not like an engine cutting through a snow drift, which might be too thick for one engine, or even two, to get through, but by putting on three or four they might force their way right through into the clear space beyond. That could not happen at all in any homogeneous haze, but something like it might happen in exceptional cases where the haze was limited in extent, so that the weaker light might, perhaps, just get through; then a more powerful light might go through and travel on, and in that way might appear to have twice the range of the weaker light. It had struck him several times, in witnessing these experiments, that the electric light was tried under less favorable circumstances than any of the others, the only reason he could suppose being that those who were already experienced in it felt perfectly sure that, tried in any way, it would prove the most powerful light. There were smaller lenses, there was the imperfection in the long leads, and one or two other circumstances; for instance, it would have been possible to work one of the arc lights with the whole Fresnel arrangement, and there was no heat given off by the arc, though with gas or oil flames that would not be possible; but the suppression of part of the Fresnel arrangement cut off some 30 per cent. of the available light.

Messrs. Kincaird & Co., engineers, Greenock, have contracted to supply, at a cost of between £2,000 to £3,000, dock gates for the San Fernando Dock Company.

THE PRESENT ASPECT OF MILD STEEL FOR SHIPBUILDING.

By JOHN WARD.

Read before the Institute of Naval Architects.

THERE are few industries in our country which, through scientific skill, have undergone such marvellous changes in so few years as the professions of shipbuilding, bridge building, and boilermaking through the successful manufacture of mild steel by the process known as the Siemens-Martin. So many able members of our institution have at previous annual meetings recorded their experience of this material, and furnished data for general guidance, that it becomes a somewhat difficult matter to say anything absolutely new or fresh on the subject. The present aspect of mild steel as applied to shipbuilding is, however, specially interesting from the fact that the relative prices of steel and iron so closely approach each other that steel steamers can now be built on the Clyde as cheaply as iron ones of the same dimensions, thus giving the owner of a steel steamer the advantages of greater deadweight, and a material which is much more reliable under all conditions of the ship's life than iron. This being so, and the firm of which I am a member having had, perhaps, as large an experience in the use of this material as any of the professional members of our institution, it may neither be uninteresting nor uninstructive if I supplement the paper read before this institution by my partner, Mr. William Denny, in 1880, and put on record a general statement of the work done by us in this material up to date, of the treatment given it in working, of total losses through failures in working, and, generally, the reasons our clients and ourselves have for our faith in this material under almost all conditions of treatment.

Since eight years ago we built the Union Company of New Zealand steamer Rotomahana, the first ocean-going merchant steamer ever built in this material, we have delivered to owners eighty steel vessels, varying in gross tonnage from 50 to 5,000 tons, and aggregating upwards of 118,000 tons gross register. We have used in their construction upwards of 51,000 tons of mild steel, made up of nearly 375,000 separate pieces of plates, angles, channels, bulbs, and bulb trees. This number is made up from the order books in which lugs and other small pieces are ordered in long lengths. If the work at present on hand in the yard is added, our tonnage and total of material used would be proportionately increased. In working this material, we have for the last five years gone on the general principle that, if steel could not stand the maximum amount of rough usage it is sure to get in a shipyard in punching, shearing, hammering, furnacing, etc., the sooner it failed, and the defects made known and remedied, the better; for were special precautions necessary for working it, as many people still believe, so surely would this necessity bring about its certain failure and rejection, as no amount of instructions would ever gain it better or different treatment at the hands of the workman than iron has always had. In this view the workman would be right, as no material striving to supplant iron should need or receive special favor. The ability of steel to stand successfully all conditions of rough usage in working is an important and necessary evidence of its suitability to resist the severe local and general strains certain to come upon it when worked into the vessel's hull.

Our total failures in working Siemens-Martin steel are divisible into two periods—(1) that up to 1880 embodied in Mr. Wm. Denny's paper of that session; and (2) since 1880 till now. The failures may be summarized as follows: In the first 7,000 tons used, embracing 58,000 separate pieces of material, six plates and one angle bar failed. In the last 48,000 tons, embracing work to date, and consisting of about 350,000 pieces, seven plates and two angle bars failed. We have often lost more than four times this amount in a single iron vessel. These results under treatment such as I have named, are worthy of as much recognition by authorities interested in steel as the occasional failures receive, and go to prove that

under conditions of local heating, or even blue (called in shipyards black) heat, failures in shipyards of Siemens Martin steel are the rare exceptions and not the rule.

Local heating without subsequent annealing, is generally condemned by most authorities on steel, including Lloyd's Register. This condemnation is at variance with the practice allowed by the latter body. In private shipyards, boiler shops, and Admiralty dockyards, local heating is largely carried on. In fact, it is almost impossible to build a vessel without a considerable amount of local heating in some sections of the work—notably all the dock beams to which knees are welded, or the ends of the plates in all water tight bulkheads, which are drawn out at the corner to admit of their fitting between the double frames. In Admiralty vessels, where the amount of water-tight joggled work is very large, it is all done under the effects of local heating. In shipyards the local heating of shell or deck plates is not usually necessary, but in boss, oxter and bridge plates it is not at all an uncommon thing, and with no apparent detrimental results.

Local heating in the construction of marine steel boilers is quite a common practice in the Clyde district, some hundreds of furnace and combustion chambers having been made by welding, and no difficulty whatever experienced with the material. Local heating by welding in this manner is found to be quite satisfactory, and even without annealing is considered an improvement over lap joints and seams of rivets, or butt straps. A more severe test of probable damage from local heating often occurs in making large steel boilers where it is almost impossible to get the plates perfectly fitted for rivetting, save by local heating and hammering close—one of the instances being where circumferential plates cross the joints of boiler fronts. Neither is it at all an uncommon occurrence the lifting of furnace crowns, which after a long voyage have, through carelessness or other cause come down. Not only are they locally heated, but severe local strains are set up owing to the lifting of the crown being done by means of a screw jack localized where the heating had taken place. Boilers used in this way seem none the worse for the treatment.

Fracture at a blue heat is known as a reality, and from the valuable tests of Mr. Barnaby some years ago, as also Mr. Stromeyer's paper recently read at the Institute of Civil Engineers, one would expect to find it of common occurrence in the shipyard. As a matter of fact this is not the case, and, so far as our experience goes, is very rare. In the eighty vessels mentioned, we have heated and bent between 35,000 and 40,000 frames and reverse frames for them, all of which have been worked during the temperatures of red to blue heat, and in almost all cases finished at a blue heat. Keel and ballast tank wing plates are flanged and worked at heats starting with red and finishing with blue heats. Boss, oxter, and bridge plates, also forward and aft plates in vessels with plate keels have often to be furnaced twice and even thrice before proper set is got. These always get a large amount of rough usage from workmen by hammering till cold, and yet with marvelously few failures. In carrying out recent experiments, the object was to test the working of ordinary steel under conditions fully equal to those involved in repairing a badly-damaged vessel, and under the before-mentioned conditions of local and blue heating, etc. Three experiments were made in our own works from ordinary steel plates taken from the stock, and dynamite and temper tender tests were made by permission of Mr. James Riley, of the Steel Company of Scotland, at their Hallside works, from ordinary ship plates of their manufacture. These dynamite tests are both exhaustive and instructive, but their severity is somewhat unnatural, and is greater than could possibly occur to a damaged steamer. The plates were only 2 feet 6 inches square, and the damage was consequently concentrated on one portion of a small area, while in the 12 to 16 feet lengths of ordinary shell plating the damage could hardly be localized to the same extent. The wonder is that plates could successfully stand such treatment, and, while the tests show the comparative results of same under conditions of cold, red and blue heats, yet the tests from actual damaged plates taken from a steel steamer and treated hot and cold are of more value as affording reliable data for guidance. It should not be forgotten that,

even after the dynamite and blue heat treatment, the steel in the immediate vicinity of the dishings is still better than average iron supplied to shipyards while tests taken from portions clear of dishing, which received a considerable amount of work at this heat, are quite satisfactory in respect to strength, ductility and bending.

The record of tests made last year from four damaged shell plates and two shell butt straps taken from a steel steamer, are especially interesting, both as a testimony to Siemens-Martin steel—of which that vessel was constructed—and for the care with which they were conducted under the most careful supervision, including representatives of Lloyd's Register. I was personally present at the investigation, and am permitted to embody the results in this paper. The objects with which these tests were made was to find out what light could be thrown upon the following propositions, and to what extent they could be verified or disproved by actual experiment: 1. That great and special attention must be paid to steel ships, because the material, steel, is of such a peculiar and novel character. 2. That damaged steel plates could not be taken off and re-rolled to go back again in their places, even steel plates in a ship twelve months old, on the ground that they would be so strained that it would not be known or seen how far they had been weakened by the straining. 3. That in a steel steamer only 12 months old, the material, when it came off, must be regarded as a second-class material, and not fit to repair the ship with; or, if put back, the vessel would not be eligible to take the 100A class again. 4. That, by cutting out the rivets in steel plates, the character of steel is very materially injured. By cutting out the rivets and cutting off the heads of the rivets with a cold chisel, a great and injurious strain is brought on the plates in the immediate vicinity of the rivet holes, altering the character of the material very much.

From the detailed analysis of the tests made there is no evidence of loss of strength or of ductility in the material in proximity to the rivet holes of landings or butts more than is to be attributed to the process of punching, rivetting, etc., and no evidence of unseen injury by straining of the ship, or by fairing or rolling, either hot or cold. The means of thirty-seven pieces taken from solid parts of plates were 28.5 tons and 24.2 per cent. extension, and of thirty-four pieces taken between holes of landings and butts 28.8 tons and 20 per cent. extension. In the construction of steel vessels built to Lloyd's rules, and receiving their highest class under special survey, the option has been, and still is, allowed of rivetting with either iron or steel rivets. As Mr. Wildish in his able paper of last session puts it, "Iron rivets in steel plates is not a desirable combination." There are sound reasons against the use of iron rivets in steel steamers (especially in the shell and decks) and only one argument in their favor, that of being cheaper. Our uniform practice has been steel rivets for steel steamers, and with ordinary treble-rivitted butts and 20 per cent. heavier straps than the plates they connected, we have not (save in one of our earliest steel steamers, built in 1879) had a single complaint as to weakness in the butts in any of them. This I can confirm from personal examination of many of them in dry dock after repeated voyages, and also from appended letters from the superintendents of some of the principal companies which have built in this material. Their experience is valuable as evidence on the important points of strength, durability, corrosion, and safety.

In the face of these facts it is difficult to know where the reason has arisen for the extra rivetting in shell and stringer butts embodied in Lloyd's rules of this year—one of the results being a decided weakening of the butts and a partial neutralizing of the advantage of a thicker butt strap. If steel vessels have been showing symptoms of weakness at the butts, have they been rivetted with iron or steel rivets, and are they many in number? Steel vessels under the rules of the late Liverpool Registry (now absorbed by Lloyd's) were compelled to be rivetted with steel rivets, and a similar practice is carried out in all recent Admiralty work. This matter will doubtless receive early recognition at the hands of Lloyd's Register, and thus give steel vessels all the benefit of constructive thoroughness they are entitled to; for, apart altogether from the difference

in the shearing strength of iron as against steel rivets, another and much more serious defect can be proved to result from the use of iron rivets either in steel or iron plates.

The series of tests of iron and steel rivets were most carried out by us in our works, and showed that, with no straining save that due to actual rivetting, caulking, and contraction in cooling, a large proportion of the iron rivets, on cutting out (after a fortnight's immersion in our dock), had fractures localized chiefly at the juncture of countersink and shank, where they broke; the shank and head, in the majority of cases, coming out altogether, while the steel rivets in every instance were absolutely free from fracture of any kind, and took from three to four times the number of blows to cut out that the iron ones did; and in almost every case the cutting out was only effected when the neck was cut completely through. The rivetting was done by journeymen, and differed in no way from work done in actual vessels, and the iron rivets were from those in use by three firms (besides ourselves) who are building vessels to highest class at Lloyd's. The cause of this investigation was the finding of a large number of apparently sound rivets (in so far as the ordinary method of testing could discover) showing blackened fractures when cut out of a damaged steel steamer rivetted with iron rivets. In cutting out a number of rivets apparently equally sound, in an undamaged iron steamer, a similar result was found, the fractures in these and in our own tests being, as in the steel steamer, principally at the juncture of countersink with shank.

The tests made from the plates in which the rivettings were done go to prove, as do also the tests made last year, that there is little difference in the nature of the material after punching and repeated rivettings, caulkings and cutting out of rivets as against punching only and without work upon it, and that even tests from the solid show but little superiority over either. It has been asserted that severe and injurious strains are brought on the plates in the immediate vicinity of the rivet holes through rivetting and cutting out. These tests show that either the annealing effect of a hot rivet counteracts this, or that the injury is purely imaginary. Local annealing or rimering, such as laid down by Lloyd's for garboards, sheer strakes, and stringers seem an undesirable nursing of steel at this period of its age, for if it be necessary to so specially treat the parts mentioned, it should be just as necessary in the bottoms, sides, and bilges. This, experience does not warrant, and probably the better plan would be to remove the special treatment laid down for those portions of the hull, and put as much proportionate faith in the goodness of Siemens-Martin steel as has, without question, been given to iron until now.

The effects of galvanizing steel plates and angles, for special work, and where cementing is admissible, is a subject with which we have experimented most carefully. In vessels designed for work in shallow rivers (of which we construct a good many) the lightest possible scantling and preservation of same from corrosion, are two of the points with which we have had to deal. We early adopted mild steel as the proper material for this type of construction, but the necessity for preservation of same from corrosion in foreign rivers was forced upon us at a later date. Preservation from corrosion, without deteriorating the material, was the object we had in view in carrying out our first series of galvanizing experiments on steel and iron plates. In the case of the former the results were most satisfactory, the advantages gained being the desired preservation, together with a slight increase of tensile strength without any material reduction in its ductility. In the case of the iron plates galvanizing had a weakening effect.

As the result of our experiments, galvanizing is now adopted by us throughout in all our special light draught work. In our most recent cellular bottomed steamers of large tonnage we have, to prevent the rapid corrosion which often takes place through the action of heat and bilge water, galvanized the plates of inner bottom which came under main boilers, and in a number of large paddle steamers we have galvanized everything under the boilers for the same reason. The experiments showing loss by pickling, also percentage of increase in weight etc., through galvanizing, were most carefully carried out by us at the Steel Company of Scotland's Blochairn and Hall-

side works, through the kind permission of Mr. Riley; while we are similarly indebted to Messrs. Beardmore for their kind permission to carry out at their Parkhead works in 1884 the tests which decided us upon the practice of galvanizing now adopted.

In conclusion, the present aspect of this material, as based on experience, is one of great encouragement both to users and makers, inasmuch as people see reason to forget, or have already forgotten, many of the fears they had at first regarding it. Our experience in eighty steel vessels launched or delivered with no special treatment or precaution different from that given to iron (save the annealing of butt straps of $\frac{8}{16}$ inch and upwards, as required in vessels classed at Lloyd's), warrants us in thus making public testimony in its favor. Basic and Bessemer mild steel for shipbuilding purposes we cannot say much about, as our experience of both has been small, but doubtless some of the members will, in the discussion on this paper, give us the benefit of their experience and the reasons for the faith they hold regarding all three processes. The whole subject is one of great and general interest to us all, and if the record of work done in Leven shipyard in this material since its adoption in 1878 is at all helpful, either in adding to the reliable data contained in the *Transactions* of this institution or of dispelling some of the fears with which this subject is often invested, then this paper will have fulfilled the purpose for which it was written.

THE EXPENSE OF RAILWAY TRANSPORT.

By LIEUT.-COL. T. F. DOWDEN, R.E., Assoc. Inst. C.E.

From "Professional Papers on Indian Engineering."

The system of special rates for freight on railways, so common in England, does not exist in India. The through rates in India are generally the sum of the local rates for each line, and these have to be so fixed as to afford a fair profit at all times. In two previous Papers, the effects of the speed of trains and of delays in working were considered, whilst the present Paper treats of the economical effect of working as a whole. In 1883 there were 10,563 miles of railway open in India; their working expenses averaged 204 rupees per day, and an average of 10.4 trains per day ran over every mile open, and the average cost accordingly was 196 rupees a train-mile. This, however, is merely an average, and does not give the cost of carriage in any particular case. The cost varies with the gauge of the railway, the gradients, the size of the engines, the amount of traffic, and the speed traveled. Railway working expenses may be divided into material and time charges, and the former vary after a certain point of speed, as the speed, and the latter vary inversely as the speed; and these charges approximate to an equality when the railway is working most economically. The decrease in cost per train-mile as the number of trains increases is large at first, but appears to approach a limit with twenty trains per day. The economy also effected by increasing the length of the trains is limited to about thirty vehicles, in the case of a given engine drawing a train up an incline of 1 in 300, at twenty miles an hour. There appears to be no advantage in increasing the load of a train, as long as there is room on the line for twenty trains per day, but beyond this point the weight of the train may be advantageously increased. If, however, this cannot be done for constructive reasons, the line may be doubled; but the saving with forty trains, in place of twenty, is small compared with the extension of traffic. The speed, however, on a double line is about double that on a single line. A speed of 29 miles an hour gives the greatest train and line capacity under the specified conditions. Steep gradients limit the capacity of goods trains, for their weight should not exceed what the engine can draw up the steepest incline

at 10 miles an hour. The stations have also to be increased, and the through speed is reduced where the gradients are long and steep. The dividend depends on the number of units of traffic carried at a profit as compared with the capital cost, and is necessarily greatest for a given unit of profit when the railway is fully utilized, though the capital cost is somewhat increased in proportion to the increased traffic. The cost of the sleepers and ballast, the rails, the rolling-stock, and the staions being each represented by 1; the cost of the works up to formation-level may amount to a sum represented by from 1 to 4, according to the country traversed. The cost of the latter works is not much affected by the gauge, whereas the former groups would need an increase of 50 per cent. for broad gauge, in place of narrow. A large capacity for traffic, though not materially reducing the working expenses when it reaches twenty trains per day for a single line, by increasing the units of profit, increases the interest on the capital. The suitable rates for freight, as gathered from the tables representing the working expenses per train-mile, and interest on capital at 4 per cent, are as follows:

SINGLE LINE.

Easy country: 6.6 trains daily.

	Rupees.
Working expenses	2.340
Interest	0.700
Total	3.040

Heavy country: 6.6 trains daily.

	Rupees.
Working expenses	2 340
Interest	1.370
Total	3.710

Easy country: 20 trains daily.

	Rupees.
Working expenses	1.810
Interest	0 330
Total	2.140

Heavy country: 20 trains daily.

	Rupees.
Working expenses	1.810
Interest	0.550
Total	2 360

DOUBLE LINE.

Easy country: 80 trains daily.

	Rupees.
Working expenses	1.520
Interest	0.135
Total	1 655

Heavy country: 80 trains daily.

	Rupees.
Working expenses	1.520
Interest	0.196
Total	1.716

Comparing a broad and a narrow-gauge railway somewhat similarly situated, such as the Great Indian Peninsula and the Rajputana-Malwa Railways, with gauges of 5½ feet and 3¼ feet respectively, it appears that the working expenses per mile open and per train-mile are less for the narrow gauge; but measured by the ton mile, the standard unit of freight, this unit on the narrow gauge costs more, owing to the smaller capacity per train, whilst certain of the charges for working trains are approximately constant, whatever their size. The relative economy of narrow and broad-gauge railways depends on a balance between the cost of working expenses and interest on the capital expenditure. It appears that it is cheaper to adopt a 5½-feet gauge for four trains a day, than a 3¼-feet gauge with eight trains, when the difference in capital cost does not exceed £1,500 per mile; whereas, with a traffic sufficient for only two broad-gauge trains, a narrow gauge would be cheaper, unless the difference in capital cost was only £250. The broad gauge is best suited for a heavy country. A comparison of a double line of 3¼-feet gauge, with a single line of 5½ feet, gives the following results:

Easy country.	Capital Cost.	Capacity.	Working Interest per Train-mile at 4 per cent.	Expenses per Train-mile.	Total per Train-mile.
	£.	Tr'ns.	Rup.	Rup.	Rup.
Double line 3¼-feet gauge	9,798	80	0.135	1.16	1.295
Single line 5½-feet gauge	6,000	20	0.330	1.81	2.140

As the carrying capacity of the broad-gauge-train is double that of the other, the freight charge per ton-mile is in the ratio of 1.07 to 1.295, or 21 per cent. more on the narrow than on the broad

gauge, in spite of the gross carrying capacity of the narrow being double that of the broad. Comparing now double lines of both gauges with equal traffic, the results are:

Easy country.	Capital Cost.	Capacity. (equal,)	Interest per train mile.	Working Expenses.	Total per Train-mile.
	£.	Trains.	Rup.	Rup.	Rup.
3½-feet gauge.	9,798	80	0.135	1.16	1.295
5½-feet gauge.	10,580	40	0.292	1.70	1.992
Heavy Country.					
3½-feet gauge.	14,298	80	0.196	1.16	1.356
5½-feet gauge.	15,500	40	0.462	1.70	2.162

The ratio per ton mile is as 1.295 to 0.996, or as 1.30 to 1 in the first case; and as 1.356 to 1.081, or as 1.25 to 1 in the second case, showing an excess of cost with the 3½-feet gauge line of 30 per cent. where the country is easy, and and of 25 per cent. in heavy country.

REPORTS OF ENGINEERING SOCIETIES.

ENGINEERS' CLUB OF PHILADELPHIA.—*Record of Regular Meeting, April 17th*, 1886.—Mr. H. W. Sanborn made some remarks on Recent Stream Gauging for the Future Water Supply of Philadelphia, describing the methods used, and why they were adopted, illustrated by numerous drawings and photographs, and the automatic recording gauge. The streams gauged were the Perkiomen Creek and tributaries in Montgomery County, the Neshaminy and tributaries and the Tohickon in Bucks County. The original intention was to gauge the minimum flow only, and for that purpose weirs were constructed on eight different streams. They were very substantially built, as they had to withstand the run of ice in the spring of the year. Heavy bed logs were placed at the level of the bed of the stream, and the superstructure built on that. They were made water-tight either by sheeting placed below the bed-log, to rock bottom, or a cement mortar wall. The crests of the weirs were generally about two feet above the beds of the streams, and were made of two-inch oak plank. Gauge boards were placed about five feet above and below the weirs, and connected, by levels, with the same. The one above indicated the depth of water on the crest. The one below was used only in case the weir was submerged by high water. The weirs varied in length from fifteen to seventy feet, according to the width of the stream. The formula used for calculating the flow over the weir was the one by Fteley & Stearns, of the American Society of Civil Engineers. Stream gauge stations were established near the weirs. Readings were taken there at the same time that they were at the weirs. When a sufficient number of readings, at various heights, were made, a "curve of flow" was plotted by a comparison of the two. Then, when the crests of the weirs were removed for the winter, the flow was found by referring the stream gauge readings to the "curve of flow."

The great fluctuation in the flow of the streams, caused by the great number of mills on them, necessitated a great many observations at the weirs to get a correct gauging. This difficulty was overcome by the use of automatic gauges. They were run by clock-work, and drew a line on a roll of paper, corresponding to the rise and fall of the stream. Two descriptions of gauges were used. One was designed chiefly by Mr. Stierle, of the U. S. Engrs. Office, Philadelphia. The minimum flows were found to be so small that the larger flows had to be determined. These had to be found by other methods, for the weirs would only carry, at the most, two feet in depth, while the water in the streams sometimes raised as high as sixteen feet. The measurements of the large flows were made mostly by the use of electric current meters. The measurements had to be made from bridges, and where none existed, in proper places, small suspension bridges were put up. One was built over the Perkiomen, at Frederick, of 120 feet span, and one over the Neshaminy, at Rush Valley, of 133 span. By means of the meter, the velocity of the water was taken at a great number of places in a line across the stream, and a close estimate of the velocity of the whole cross section determined. Stream gauges were placed near the meter stations, to be read when measurements were made, answering the same purpose as those connected with the weirs.

In some cases, large flows were measured by getting the velocity of the stream, by means of pole floats. When used, care was taken to have the length of them as near the depth of the water as possible, and they were run at as many stations across the stream, as was necessitated by the changes in the even flow of the stream. The rise and fall of the water during freshets was so sudden, and the stations, eleven in number, were so scattered—the water-sheds covering five hundred square miles—that it was impossible to get to, and make measurements of, more than one or two streams during a freshet. Then, many times, the freshets would come in the night, and nothing could be done but the taking of continuous readings of the stream gauges.

To overcome these difficulties with our small force, and get at least fair measurements of all the streams at the high point of a freshet, "maximum stream gauges" were set up on most of the streams. A place was chosen where the bed of the stream was uniform in width and slope, and two similar gauges set up. They were usually from two hundred to five hundred feet apart. They were made in the form of a box from eight to twelve feet long, and six inches square inside. One side opened as a door. They were placed on end and shielded and supported by heavy timbers imbedded in the soil or bolted to the rock bottom. Vertically though the center of the box ran a brass rod, which was graduated. A metallic float ran on the rod in such a manner that it would rise with the water, but would remain fixed on the rod, at the highest point the water

reached, after it had fallen. The two gauges were connected by levels, and from the gauge readings the slope of the water was determined. From this the velocity of the stream was found by the Kutter formula. The daily flows of all the streams have been tabulated, from the commencement of the gauging in July, 1883, to January 1st, 1886, and the field is still being continued. The daily flows have also been shown graphically on sheets, with the rainfall on the water shed and the temperature annexed. The connection between the three is well shown. Rain-gauge stations were established over all the water sheds, and the data obtained from them, combined with that from previously exis ing gauges, which was kindly furnished us by the observers, have also been plotted graphically, showing plainly the variations of the rainfall over large areas. Three automatic rain-gauges were used to show the intensity of the storms.

Mr. E. V. d'Invilliers spoke upon the geological position, characteristic features and method of mining the ore at the Cornwall Iron Mines, Lebanon Co., Pa., illustrating his remarks with several maps and cross-sections, and a relief model of the mines and contiguous territory, constructed by Mr. A. E. Lehman.

Mr. A. E. Lehman then exhibited, and described the method of construction of, the Model of the above mine. It is built entirely of layers of cardboard, the perpendicular edges of which are brought to slope by engraving tools. It was so constructed that the accurate location of the contour lines was preserved, and they were drawn in ink on the finished surface, adding greatly to its practical value and intelligibility. Property lines, railroads and other topographical features and areas are shown in ink and color. The whole work is one of remarkable neatness.

Record of Business Meeting, May 1st, 1886.—Mr. Frederic Graff presented Notes Upon the Early History of the Employment of Water Power for Supplying the City with Water, and the Building and Rebuilding of the Dam at Fairmount.

The following paragraphs occur: The earliest official publication referring to the use of water power for the supply of Philadelphia with water, is contained in a report made by Messrs. John Davis and Frederick Graff, Dec. 18th, 1811, in pursuance of a resolution passed by Councils, Oct. 24th, 1811. After reporting upon the bad condition and inadequacy of the steam works then in use, at Chestnut street, on the Schuylkill, and at Centre Square, they considered the propriety of building new steam works on the Schuylkill at the Upper Ferry Bridge, and thereby supplying water to a reservoir to be built on "Morris' Hill," now Fairmount.

February 5th, 1819, the "Watering Committee" made a report, in which the following words occur: "The constant and great expense attending steam engines, and the vexation occasioned by repeated accidents, have always been present to the Watering Committee, who have ever thought water power should be resorted to, if practicable. The present Committee have been fully alive to the importance of the subject; and their desire of accomplishing it more and more excited by the success of the improvement of the Schuylkill, by dams and locks, which suggested the practicability of erecting a dam and water works near Fairmount."

At that time there was but little experience in building dams, except upon very small mill streams. The Committee asked for plans and estimates for a dam and the necessary lock, and such were submitted by Mr. Thomas Oakes, Messrs. Lehman and Briggs, Mr. Lewis Wernwag, who had built the bridge at Fairmount, Mr. Frederick Graff, the engineer of the works, and Mr. Ariel Cooley.

I herewith call your attention to a drawing copied from the originals, formerly in the office of the Water Department, combined on one sheet, of the sections and plans for the dam, as proposed by all the above named, except Mr. Wernwag. No material for his plan could be found at the date when the drawing was made.

All the plans, except that of Mr. Cooley, were upon the arched form, the chord line varying from 720 feet—that of Mr. Wernwag—to 1,000 feet—that of Messrs. Briggs and Lehman.

The plan proposed by Mr. Graff was for substantial framed wooden cribs, sunk through the mud in the deep water to the rock bottom, sheet piled at the back, and reinforced by rip-rap of stone in front and stone and earth at the back.

Mr. Wernwag's was somewhat similar, but without the sheet-pile, or rip-rap in front.

Mr. Oakes dam was to be formed by a planked box or open coffer dam from about low tide to the bottom of the river. This was intended to have been about 12 feet wide up and down stream, and in deep water would have been about 30 feet deep—filled with what was termed "shingle grouting." Upon this was to have been built a framed timber dam, extending about 35 feet up stream, filled with stone, and decked with plank on up and down stream faces, the whole rip-rapped with stone back and front.

Messrs. Brigg's and Lehman's plan was for a pile of earth and stone from low tide to the bottom of the river, about 30 feet deep; upon this was to have been built a framed timber dam, with a triangular section, and base of about 45 feet, filled with stone and decked back and front.

All these would have to be sunk through about 11 feet of mud in the deepest part of the river to solid rock.

Mr. Wernwag's plan contemplated putting the canal upon the east side of the river, and an extension of the present forebay of the works, which would, of course, have been very objectionable and detrimental to the purity of the water supply, on account of the traffic carried on through the forebay, to reach the canal.

After some negotiation, a contract was made with Mr. Cooley for the erection of the dam, locks for the navigation, and the forebay with its head arches for the supply of the wheels and pumps of the water works, for the sum of one hundred and fifty thousand dollars. His plan, upon which the dam was built, was as

follows: The dam was all upon the rock, extending diagonally up stream, the overfall was 1,204 feet long, with a mound dam, on the east end, of 270 feet; it was made of cribs of round hemlock timber, sunk in the deep water which extended about four hundred and fifty feet in length, to the depth of 31 feet from the comb of the dam; in the deep water the cribs were 40 to 50 feet long up stream, and about 17 feet wide; in the shallow water and where they were on rock, dry at low tide, they were from 20 to 25 feet long up stream; they were filled with stone and planked on the up stream ends and top with three inch hemlock joists; the whole was backed and covered over the top surface of the dam with stone, rubble and gravel.

Mr. Cooley's first soundings were made on February 21st, 1819; the building of the dam was commenced April 19th, 1819; the last crib was sunk June 25th, 1821.

The water flowed over it for the first time July 23d, 1821. The use of the steam engines was discontinued and the whole supply pumped by the water wheels October 25th, 1822. This dam, which was very imperfectly built, mostly of small sized round hemlock logs, put together with two inch wooden treenails, became so much decayed as to be declared unsafe; and on the 2d of May, 1842, the work of its entire reconstruction, above low water mark, was commenced by day's work under a general superintendent and a wharf builder, Frederick Graff, Senior, being at the time the Chief Engineer of the Water Department. The old dam was entirely removed from low tide up, the timbers being so much decayed that they were only held in place by the stone filling. The old cribs below low tide having been constantly submerged, were sound, and therefore were allowed to remain, after being decked over with heavy white oak logs; upon this the new dam was constructed.

The whole of the new structure is of white pine, framed and bolted together with wrought iron spikes; after being carefully packed with stone, a deck of white oak was put upon it.

In 1871 efforts were made to obtain appropriations for building a stone dam, instead of that built of timber in 1872; but the sum estimated to do this was considered too high, and for that and other reasons the project was abandoned.

ENGINEERING NOTES.

DRAINING MACHINERY IN THE VALLEY OF THE PO.—The Valley of the Po, the most extensively and most admirably irrigated district in the world, is not less remarkable for the importance and the excellence of the drainage works executed in recent years. In less than 30 years, from 1850 to 1879, upwards of 600,000 acres of marshy land in the provinces of Venetia and Emilia alone, have been drained and transformed into rich country. The long lines of chimneys bordering the Canal Bianco belonging to steam elevating-machinery, remind one of a Lancashire district. The question of drainage has from all time occupied the attention of the population of these Adriatic districts; but, in consequence of the difficulty and more often the impossibility of drainage by natural flow, it is only since the advent of steam that the work of drainage has been thoroughly performed.

Drainage by machinery in the valley of the Po is almost entirely carried out on one uniform plan. The ground to be drained is fenced round by catch-water trenches or canals. Occasionally, when necessary to prevent infiltration, the bottom of the canal is deeply trenched and filled with clay. Within the circumscribed territory a system of drains is cut, in which the water is conducted to the lowest level at a point conveniently selected, where the elevator is erected. By the elevator the water is lifted into a canal or a river, in which it is carried off by gravitation. The elevators have to deal with variable volumes of water at variable heights; but, in general, the greater the height, the less the quantity to be lifted, so that the work to be done is in some sort constant. The heights vary generally in the ratio of 1 to 3.

Three systems of machines exclusively are employed as elevators: centrifugal pumps, turbines (*rouets*), and lifting-wheels (*roues élevatoires*). All of these machines are moved by steam-power, and they are the most economical. Piston-pumps employed to raise large quantities of water through small heights have shown not more than 35 per cent of efficiency. Centrifugal pumps are of great variety of form, differing principally in the shape of the blades. The turbine is only a centrifugal pump on a vertical axis, of which the pipes are replaced by the sides of a well. It consists essentially of a circular crown-plate on a vertical shaft, on the under-side of which the blades of a centrifugal pump are fixed. In some instances, the blades, instead of being free at their lower parts, are fixed to a circular plate having a central opening equal to that left by the crown plate. The wheel is placed low enough to be submerged at all levels of the water. It is driven by toothed gearing or by bands. The difference between the turbine (*rouet*) and the centrifugal pump, is that the passages for water are much larger in the first than in the second. Consequently the velocity of the water is less and occasions less friction, whilst the water escapes more freely. For small quantities of water, the pumps are more economical than the turbines, as the cost of construction of wells is saved. The turbines adapt themselves to great variation of level, whilst maintaining a high ratio of efficiency—about 75 per cent. Speed is, according to one system, altered by means of changes of toothed-wheel gearing to suit the various levels. According to another system, the speed is maintained constant for different levels, but the efficiency may fall as low as 60 per cent.

For this reason, in the Po valley centrifugal pumps and turbines are being gradually replaced by lifting-wheels. These wheels are arranged like undershot water-wheels, but with the reverse action that the water is raised by the wheel. Originally, the blades or floats were straight and radial, and the wheels were of low

efficiency—about 30 per cent. They dashed the water about as each blade entered it; whence their Italian name of *ruote a schiaffo* (literally, slapping wheels). The blades are now inclined at about 60° to the radius, and are formed with a double curvature, so that the water is lifted without agitation or useless elevation; and by means of a sliding iron shutter the opening for access of water to the wheel is formed at the lower part only. The efficiency is increased as the difference of levels is increased, and it averages 80 per cent. The wheels manufactured by Mr. Zangilorami are constructed entirely of iron, and some of them are made as much as 39 feet in diameter. The side walls are exactly dressed with a clearance off the wheels at most of one centimetre, or $\frac{4}{10}$ inch. The minimum immersion is 20 inches for a wheel of 23 feet. The circumferential velocity is constant—about 57 inches per second.—*Abstract of Institution of Civil Engineers.*

THE DEEPEST BORE-HOLE IN THE WORLD.—The deepest bore-hole in the world is at Schladebach, near Kötschau station, on the railway between Corbetha and Leipzig, and has been undertaken by the Prussian Government in search for coal. The apparatus used is a diamond drill, down the hollow shaft of which water is forced, rising again to the surface outside the shaft of the drill, and inside the tube in which the drill works. By this method cores of about 50 feet in length have been obtained. The average length bored in 24 hours is from 20 to 33 feet, but under favorable circumstances as much as 180 feet has been bored in that time.

DEPTHS OF VARIOUS BORE-HOLES.

Name of Place.	Depth in Feet.
Domnitz, near Wettin	3,287
Probat-Jesar, Mecklenburg	3,957
Sperenberg, near Zossen	4,173
Unseburg " Stassfurt	4,242
Lieth-Elmshorn, Holstein	4,390
Schladebach	4,515

The dimensions of the bore-hole at Schladebach are as follows:

Total depth. Feet.	Depth. Feet.	Diameter. Inches.
189.6	189.6	11.0
605.7	416.1	9.0
661.8	56.1	7.3
1906.5	1244.7	4.7
2259.8	353.3	3.6
3543.4	1283.6	2.8
4039.9	526.5	1.97
4514.6	444.7	1.88

The various strata passed through are as follows:

	Feet.
Soil and sand, about	16
Clay	66
Sandstone (Bunter)	459
Anhydrite	59
Brine spring	—
Magnesian limestone (Zechstein)	144
Gypsum	36
Anhydrite	295
Marl-slate (Kupfersheifer)	3
Sandstone (Rothliegendes)	3,435

The bore-hole, which in January, 1885, had reached a depth of 4,560 feet, was commenced in June, 1880, but left after a year's work, recommenced at the end of 1882, and is still progressing. The cost up to January, 1885, was about £5,000.—*Abstracts of Institution of Civil Engineers.*

IRON AND STEEL NOTES.

THE annual statistical report of the American Iron and Steel Association has just been published in pamphlet form by the Association, 261 South Fourth Street, Philadelphia. It contains complete statistics of the American iron trade for 1885 and previous years, and a brief review of the present condition of the iron industry in foreign countries. The following table shows the production of iron and steel in the United States for the years 1884 and 1885:

Products.	Net tons. (Except nails.) 1884.	1885.	Increase or decrease per cent.
Pig iron	4,589,613	4,529,869	− 1
All kinds of rolled iron, except rails.	1,931,747	1,789,711	− 7
Bessemer steel rails	1,116,621	1,074,607	− 4
Open-hearth steel rails	2,670	4,793	+80
Iron rails	25,560	14,815	−42
Kegs of iron and steel cut nails	7,581,379	6,696,815	−12
Crucible steel ingots	59,662	64,511	+ 8
Open-hearth steel ingots	131,617	149,381	+13
Bessemer steel ingots	1,540,595	1,701,762	+10
Blooms from ore, pig iron and scrap	57,005	41,700	−27

RAILWAY NOTES.

"IT is understood that the Metropolitan Railway Company is the latest English line which has determined to adopt the steel sleeper, and that Messrs. Bolckow, Vaughan & Co., and a Welsh firm, are the concerns who have shared the first order for that line. It is gratifying that native steel-masters can now offer metal sleepers at prices more favorable than those of the German and Belgian makers, and of a superior quality."

RAILWAY intercommunication between the Australian colonies is rapidly extending. It is expected that the South Australian portion of the International Railway will be completed about the end of April. Two new engines for the new line have arrived from Messrs. Dubs & Co., Glasgow. They are very powerful engines specially suited for hill traffic. The four sleeping cars were, at date of recent mail, expected to arrive shortly from America. They are de

scribed as large, handsome carriages, with every accommodation for travelers overland to and from Victoria.

HIGH-SPEED ENGINES.—At the meeting of the Society of Engineers held on April 5, a paper was read on "Obscure Effects of Reciprocation in High-speed Engines," by Mr. Arthur Rigg, past president The author referred to the mathematical investigations of Mr. Charles T. Porter, as being the first to show how the reciprocating motion in a high-speed engine could be used to equalize pressure and conduce to smooth running; and to the engine, based on that principle, which excited great interest in the London exhibition of 1862. The text books of which the knowledge was assumed were Mr. C. T. Porter's book on the indicator, and the author's "Practical Treatise on the Steam Engine." The field of improvement opened out by Mr. Porter had not, however, been cultivated as might have been expected, and the majority of high speed engines were either so only in name, or if run at really high speeds were practically hammering themselves to pieces. In small engines these dynamical effects were insignificant, except at extremely high speeds, but in larger engines their importance rapidly increased. No true engineer ought to be content without discovering why one engine ran smoothly and another uneasily, or why an engine that ran well at ordinary speeds behaved badly at high speeds. Since 1872 the author has had exceptional opportunities of investigating those important questions, and gave in his paper some of the results he had arrived at. The two classes of engines investigated were the Porter-Allen engine and some designed by himself. In each case all the weights of the reciprocating parts were known, and the effects of their movements were graphically shown in diagrams, and the work of constructing those graphical diagrams was simply explained. A table of useful constants was given, and also another table summarizing the data and exhibiting in numerals the ratios and results. The table showed distinctly the great divergence in results in different engines, and from it and the graphical diagrams could be clearly seen the errors in design to be avoided Engineers understood pretty well the necessity of having enough initial pressure, but sufficient attention had not been given to the heavy strains at the end of the stroke, arising from the momentum of the reciprocating parts Of the forces that could arrest those strains one only, that of a cushion of exhaust steam, could do so without injury. The proper changes were explained and the effects they would produce were deduced on the same principles as before, and compared with the effects of the original designs. It was thus shown how such engines could be made to run at high speeds with ease and security, and engineers were urged to apply the new diagrams to the engines in their charge, and to ascertain what changes were required, so that the working days of the engine might be passed in quietude, its life prolonged, and their own anxieties in no small measure diminished. The paper was amply illustrated by diagrams, and in the discussion which followed the challenge thrown out by Mr. Rigg to the makers of the modern class of high-speed engines was by no means responded to in the manner that had been anticipated. The representatives of such engines, who, the president observed, had been invited to hear the paper read and to take part in the discussion, were conspicuous by their absence or their silence.

A NEW ALPINE TUNNEL AND RAILWAY.—There are at present half a dozen or more projects for crossing the various chains of the Alps under consideration or proposed. Besides the several purely Swiss undertakings, the much-discussed Mont Blanc project, the proposals of Baron von Vautheleret for constructing a railway over the Great St. Bernhard, and the plan of Colonel de Bange, there are a number of different projects for tunnelling through the Simplon, by Herr Jean Meyer. Amongst the various proposals for tunnelling through the Simplon may also be mentioned that the plan of the Société Cécil, Paris. Instead of a long tunnel (19,900 metres, or 12¼ miles) at the foot of the Simplon, the company would construct a tunnel only 4,800 metres (3 miles) long, near the summit, at the elevation of 1,700 metres (5,576 feet). The approaches on both sides of the tunnel would in that case have an ascent of 1 in 10, and this rise would have to be overcome by means of a rack railway. The latest scheme for an Alpine railway is that by Herr Roman Abt, of Bünzen (canton of Aargau), who comes forward with an undertaking presenting novel features, and which is likely to attract considerable attention. Herr Abt proposes to connec Brieg, the terminus of the Simplon Railway, with Airolo, and thus provide the St. Gotthard Railway, instead of a competitor, with a new feeder. He does not intend to go with his railway beyond the Swiss frontier; on the contrary, he supplies railway communication between Upper Valais and the Val Bedretto, gives Switzerland an important strategical line, and all this he undertakes to effect at a cost much below any of the other schemes mentioned above. Herr Abt has described and illustrated his project in a pamphlet, which he has submitted to the Swiss federal council, and from which we learn that his railway will branch off at the station of Brieg, at a height of 679.5 metres (2,229 feet) above sea-level, and follow for 35 kilometres (22 miles) the course of the Rhône as far as Obergestelen. The ascent of the rise at Grengiols is to be by means of a rack railway 5 kilometres (3 miles) long, having an ascent of 45 per 1,000. The remainder of the line up the Rhône valley is by an ordinary railway, with a maximum rise of 25 per 1,000. The Rhône is crossed at Obergestelen, and the ascent of the left slope, as well as the entry into the Gerenthal, is effected by means of another rack railway, 6 kilometres (3¾ miles) long, and having a rise of 60 per 1,000. The Alpine tunnel commences in the Gerenthal, at an elevation of 1,715 metres (5,625 feet), and passes under the Kuhbodenhorn, the length of tunnel being 6.3 kilometres (4 miles). The northern ascent of the line through the tunnel is 1 per 1,000, the southern descent 15 per 1,000. The mountains here consist of the best granite of the St.

Gotthard *massif*, so that Herr Abt assumes the usual tunnel lining may be dispensed with. From the southern tunnel entrance, 1,664 metres (5,361 feet) above sea-level, the railway passes along the left bank of the Ticino through the Val Bedretto, and reaches Airolo station at an elevation of 1,144.8 metres (3,785 feet). This portion of the line comprises two bits of rack railway, of a total length of 7.65 kilometres (4¾ miles), and with a descent of 60 per 1,000. The intervening stretch (3 kilometres, or 2 miles) is ordinary railway, with a fall of 20 per 1,000. The total length of the whole line is 61 kilometres (38 miles). The probable cost of the railway, which is to be a single line, is estimated by Herr Abt at about 23,000,000 francs (£920,000). Amongst the various advantages claimed for the new railway may be mentioned that the Western Railway of Switzerland will be brought into direct communication with Italy, the line from St. Moriz to Brieg, a cul de sac, being turned into an important national highway. The Rhone valley and Upper Valais will be opened up, and, what is of equal value, a useful feeder will be supplied for the St. Gotthard Railway, whilst the solution of the Simplon problem will be in no wise prejudiced, on the contrary, brought nearer its consummation. Finally, Switzerland will gain politically, for a railway of the utmost strategical value to her will be supplied, by means of which it would be possible to transport an army of 2 ,000 men from Lausanne to Airolo in twenty-four hours. The fortifications contemplated on the southern slopes of the St. Gotthard would gain additional importance, as they would be considerably strengthened by the new line.

On the Principal Methods Adopted for Insuring the Safety of Trains upon Italian Railways.—The traffic upon the Italian lines is not sufficient to require the adoption of the block system.

Trains following one another upon the same line of rails.—As a general rule a ten-minute interval is allowed between the departure of the trains. If the speed of the second train is greater than that of the first, this interval is increased to fifteen or twenty minutes A slow train must wait in a siding for a quick train to pass it unless it can reach another passing station at least fifteen minutes before the quick train is due there. On some lines, however, a luggage train is allowed to follow a passenger train at an interval of five minutes; on other lines the ten minutes interval applies to all trains. Trains, after leaving the station, are protected by signals for the prescribed times. Upon gradients of 25 per thousand or more no train is allowed to leave a station till informed by telegraph of the arrival of the preceding train at the next station. That these regulations are sufficient for insuring safety may be seen from the fact that during the ten years 1873–82, there were on the Upper Italian Railways (which have the heaviest traffic in the kingdom) only three collisions between following trains, all of which were caused by negligence. This corresponds to one collision per 55,000,000 train-kilometres. The average number of trains per day in the same direction upon this system is fifteen, and the maximum thirty-five.

Trains running in opposite directions upon a single line.—As a general rule these trains are run according to the time-tables without any special precautions. Notice of the departure of a train is telegraphed to the next station. If a train is more than a quater of an hour late the fact is notified to all stations up to that at which it ought to have arrived. When a train is so late as to render necessary an alteration in the arrangements for passing another train traveling in the opposite direction, the alteration, after being determined, is telegraphed to the other stations affected by it, and acknowledged by them, and the station-master at each place is bound to sign a register kept for the purpose, in which the alteration is noted. The engine-drivers and guards of the trains receive and sign written orders in respect of the alteration. This being the system in use, the station signals, except when the traffic is heavy, stand, as a rule, at "line clear." The system has the defect that it depends for its working entirely upon the attention of the railway servants. On some lines electric-bell signals have been adopted, and a description of several ways of working them is given in the paper.

The Westinghouse and Smith-Hardy continuous brakes have been adopted to a small extent during the last five years, but no decision has yet been come to as to their respective merits.

Special precautions are taken to prevent accidents in tunnels: when these are short their two ends are protected by signalmen, and when long they are divided into lengths by signal-boxes inside the tunnels.

Bell signals are used at level crossings where there is much traffic. There is a law that the gates are always to be closed five minutes before the arrival of a train, and when the gate-keeper has nothing but the time-table to guide him, if a train is late the gate has to be closed from five minutes before it is due till it has actually passed. This, of course, is a great annoyance to persons traveling on the road. To obviate this inconvenience two bells are placed in the gatehouse, one for up and one for down trains. These bells are in electric communication with the nearest stations, or signal-boxes, and warn the keeper of the approach of a train in either direction. Disk signals are placed 500 metres from the crossing in both directions and are set against the trains while the gate is open.

For the protection of trains upon steep gradients, a simple electric system has lately been introduced on lines with little traffic. A continuous current is established between two stations, and current-breakers are placed in each of the guard-houses between the stations, by which the men can signal to the stations. In the event of a train or a part of one running away down the incline, a signal can be sent to that effect to the nearest station. Another signal notifies that an accident has happened and that a breakdown engine is required.

Swing-Bridges.—Guards are stationed at each end of an opening bridge, and it is the duty of a guard when a train approaches the bridge to get on the engine, and pass over with it.

Stations.—Up to the last few years, even at the larger stations, very simple signals were

found sufficient, and these were independent of the points, but at many of the principal stations the traffic has now outgrown the original arrangements and interlocking points and signals are being introduced.—*Abstracts of Institute of Civil Engineers.*

ORDNANCE AND NAVAL.

According to *Engineering*, the steamships Parthia and Batavia have been made much more economical by putting in triple expansion engines. The Parthia formerly burned 47 tons of coal a day of 24 hours in making 11 knots. During 1885-6 the consumption was 25 tons at the same speed. The Batavia gives still better results, reducing from 40 tons for 11 knots to 21 tons.

Such of our readers as are interested in artillery matters have probably noticed a paragraph in the London *Times*, stating that the new Krupp guns placed in the Dardanelles forts have signally failed, "some bursting, killing several gunners, and others being utterly unfit for their intended use as to range and precision." We have made inquiry, and cannot find any substantial foundation for this report. Officers remaining in Constantinople on their way back from the Bucharest trials know nothing of it. It does not appear likely that Krupp guns would suddenly be found to fail in three totally different respects, namely, in strength, range, and in accurate shooting. Probably some accident may have occurred which has given rise to this report, but the report in the above shape may be safely rejected.

On 28th inst. the steamship Talisman, which has just been built by Messrs. R. & W. Hawthorn, Leslie & Co., Hepburn, to the order of the Ocean Steamship Co., and engined by Messrs. Robert Stephenson & Co., Newcastle, had a very successful trial on the measured mile at Hartley. The dimensions of the vessel are as follows: Length, 320 ft.; breadth, 36 ft.; and depth, 27 ft. 9 in. Her engines are of the Holt's tandem design, having cylinders 27 in. and 58 in. diameter, with a stroke of 5 ft., and indicating 1265 horse-power. Steam of 80 lbs. pressure is supplied from one large double ended steel boiler, of a total weight of 75 tons, and this is fitted with Fox's patent corrugated furnaces. A mean result of 12¼ knots was attained at full speed during several runs, and the engines worked most smoothly, and were easily handled.

BOOK NOTICES.

Publications Received.

Proceedings of the Institution of Civil Engineers.

Paper No. 2070, on the Theory of the Indicator and the Error in Indicator Diagrams, by Osborne Reynolds, M.A., LL.D.

Paper No. 2083, on Gas Producers, by Frederick John Rowan.

Paper No. 2091, Removal of Shoals by Propeller-Sluicing on the Columbia River, by Harry Hawgood. Assoc. M. Inst. C. E.

Paper No. 2139, the Injurious Effect of a Blue Heat on Steel and Iron, by C. E. Stromeyer, Assoc. M. Inst. C. E.

Abstracts of Papers in Foreign Transactions and Periodicals.

Cassell's National Library, vols. 1 to 15, edited by Professor Henry Morley, LL.D.

My Ten Years' Imprisonment, by Silvio Pellico.

Child Harold's Pilgrimage, by Lord Byron.

The Autobiography of Benjamin Franklin.

The Complete Angler, by Isaac Walton.

The Man of Feeling, by Henry Mackenzie.

The School for Scandal, and The Rivals, by Richard Brinsley Sheridan.

Sermons on the Card, and other Discourses, by Bishop Latimer.

Plutarch's Lives of Alexander and Cæsar.

Castle of Otranto, by Horace Walpole.

Voyages and Travels, by Sir John Maundeville.

She Stoops to Conquer, and The Good-Natured Man, by Oliver Goldsmith.

The Adventures of Baron Trenck, translated from the German, by Thomas Holcroft, Vol. I.

The Adventures of Baron Trenck, Vol II.

The Lady of the Lake, by Sir Walter Scott, Bart.

Luther's Table Talk.

A Popular History of Astronomy During the Nineteenth Century. By Agnes M. Clerke. New York: Macmillan & Co.

We venture to assert that all who feel tempted by the title of this book to begin the perusal of it will find it difficult to lay it aside without finishing it.

The authoress says of her work: "It embodies an attempt to enable the ordinary reader to follow with intelligent interest the course of modern astronomical inquiries, and to realize (so far as it can at present be realized) the full effect of the comprehensive change in the whole aspect, purposes, and methods of celestial science, introduced by the momentous discovery of spectrum analysis."

It is certainly a valuable and an attractive addition to scientific literature.

A Course on the Stresses in Bridge and Roof Trusses, Arched Ribs and Suspension Bridges. By William H. Burr, C. E. Third Edition. New York: John Wiley & Sons.

The first edition of this excellent work was published in 1880. The present edition differs in a few points for reasons thus explained by the author: Since the publication of the first edition of this book, engineering practice in iron and steel construction, especially in the department of bridge building, has made very material progress. The distribution of metal in pier structures has been considerably modified so as to produce concentrations in larger numbers; but chiefly the treatment of moving loads has experienced such a radical transformation as to bring it to a thoroughly rational basis. Hence portions of the book as originally written have been canceled, and replaced

by entirely new matter so amplified and extended as to bring the work in all its details abreast of the best practice of the present day.

A TREATISE ON ELEMENTARY STATICS.—By JOHN GREAVES, M.A. London: Macmillan & Co.

This treatise is based on the idea that the Laws of Motion form the only satisfac'ory basis on which the science of Statics can be built.

The author deduces the parallelogram of forces from the Newtonian definition of force and the parallelogram of velocities, and thus obtains the necessary conditions of equilibrium for any material system by means of the third law, without assuming the transmissibility or supposing the system to become rigid. From these and certain geometrical considerations follow the sufficient conditions of equilibrium of a rigid body.

The order of topics is as follows: Statics of a Single Particle. Statics of Systems of Particles. Statics of Constrained Bodies. Centers of Mass. Friction. Virtual Work. Machines.

An Appendix dealing with indefinitely small quantities has been added to enable the student who is unacquainted with the calculus to follow the methods employed in the chapters on Center of Mass, and Virtual Work.

MISCELLANEOUS.

AT a recent meeting of the Paris Academy of Sciences a paper was read on "The Constitution of the Earth's Crust," by M. Faye. It is argued that the surface of the globe cools more rapidly and to greater depth under the oceans than on the continents, because heat radiates more freely through liquid than through solid bodies. And as this discrepancy has existed for millions of years, the crust of the earth must now be denser under the waters than under dry land. Hence, in the pendulum observations and other calculations made relative to the figure of the globe, no account should be taken of the attraction of the continental masses lying above sea-level, this excess of matter being compensated lower down by a corresponding diminution of density. In the same way no account should be taken of the feeble attraction of the oceans, because this also is compensated a little lower down by the greater density of the solid crust under the oceanic basins. The same conclusion is pointed at by the now completed triangulation of India, Col. Clarke remarking that it would seem that these pendulum observations have established the fact—previously indicated by the astronomical observations of latitude in India—that there exists some unknown cause, or distribution of matter, which counteracts the attraction of the visible mountain masses.

MINERAL lubricating oils are often adulterated by the addition of cheap oils. The following tests by Herr P. Falke, published in the *Journal of the Society of Chemical Industry*, may serve for ascertaining their purity:—(1) Color. The oil must be perfectly clear, and as light as possible. It should not be turbid, which may be caused by the presence of water or other substances. If the oil be turbid by water, it froths on heating, whereas a turbidity produced by solid matters, such as paraffin, disappears on warming, and reappears on cooling. The characteristic feature of all mineral oils is their blue fluorescence. (2) Smell. The smell must be as little perceptible as possible, and should not increase on warming the oil. It mostly smells like petroleum. (3) Behavior on shaking with water. If three parts of oil be shaken with one part of water in a test tube, warmed, and allowed to stand in a water-bath for some time, no emulsion must appear between water and oil, but the latter should stand clear above the water, which should opalesce only very faintly, and be perfectly neutral. (4) Behavior to caustic soda. The oil should not be attacked by a caustic lye of 1.40 sp. gr., neither in the cold nor on warming. Saponification is a certain evidence of the presence of animal or vegetable fat. (5) Behavior to sulphuric acid. On mixing the oil with sulphuric acid of 1.60 sp. gr. it must not be colored brown, but yellow at the most; otherwise resins have not been carefully removed. (6) Behavior to nitric acid. On mixing oil with nitric acid of 1.45 sp. gr. a rise of temperature takes place, which should not exceed a certain limit. (7) Specific gravity. Although the specific gravity of oils suitable for lubricating purposes varies from 0.875 to 0.950, only a very small latitude—0.003 at the most—is permitted in contracts. It is invariably taken at 15° C. (8) Behavior on exposure to the air and heat. Spread in a thin layer and exposed to the air for some time, its consistency must not change, nor should it become acid on being heated continuously above 150°. Heated in open vessels it should not give off combustible vapors, except at a high temperature, which is usually specified in contracts. Its flashing point should be ascertained in Abel's apparatus. (9) Behavior at a low temperature. It should bear a low temperature without losing its lubricating power, nor should it become solid even at a very great cold, but it should rather assume the appearance of an ointment. (10) Test for consistency. This determination is most important. The velocity of efflux of pure rape-seed oil is taken as a standard, and that of the mineral oil compared with it. 100 cc. of the sample are allowed to flow out of a burette with tap, while the time which is required is noted down.

THE following is suggested in the *Electrician* as a perfectly fair arc lamp carbon test:—Take a dynamo machine, with its full complement of lamps, and trim the lamps with the same make of carbons; note the speed of the dynamo carefully, and during the test measure the current at frequent intervals with an ammeter; see that all the lamps burn freely, without hissing, and yet not with arcs so long as to flame. Measure the electro-motive force around each arc with a voltmeter. Burn the lamps until all the carbons are consumed, or burn them, say, for four hours, and then measure the length of carbons consumed, and calculate the total time that they would burn, taking the average result. In testing another make of carbon pursue the same course. You will now be able to note the difference between various grades of

carbons. Some carbons will be soft, and will consume so rapidly as to make them uneconomical; others will be of such high resistance that the machine will not run its full complement of lamps with good long arcs, without increasing its speed. In such a case a lamp or two could be cut out of the circuit until the arcs are normal, and this would show the degree of economy of the first carbons over the others. It is not infrequently the custom to mix several different brands of carbons on the same circuit of lamps, and then judge of the results entirely by the length of time each carbon burns. Nothing could be further from a real test. A carbon which would burn nine hours would frequently be less economical than a carbon burning eight hours; as generally the latter carbon would enable you to burn, say, two more lamps on a thirty-light circuit than the former. Calculating the rental receipts from these two lamps, it would be found that they would more than make up the difference due to more rapid consumption of the eight-hour carbons.

A NEW method for producing hydrogen gas been described. Superheated steam is passed through red-hot coke in a retort. The result is a mixture of hydrogen and carbonic oxide, or what is known as water gas. These gases are then passed on into a second retort, strongly heated, in which a quantity of some refractory substance, such as firebrick, is placed. At the same time jets of steam superheated to the point of dissociation are passed into the retort, the result being a mixture of carbon dioxide and a double amount of hydrogen. The carbon dioxide can be absorbed by passing through milk of lime, and thus pure hydrogen be obtained and collected in a gas holder. One ton of coke is stated to correspond to 3,200 cubic metres of gas, and the cost is given as 0.015 franc per cubic metre.

THE plans and proposal of Mr. W. H. Radford, C.E., of Nottingham, for the drainage of Newhaven have been accepted. Eighteen competitive plans were sent in. The scheme retains those sewers which are in good condition, and utilises the remainder for surface water only. New well-ventilated and flushed sewers will be placed on those streets where they are required. The sewage from the town on the west of the river will be conveyed by a main outfall to a point away from the town and near the mouth of the river, where it will impound in a concrete storage tank during high tide. The sewage will then be run into the mouth of the tidal river at half ebb, so as to take advantage of the powerful seaward current, and the last remnant of the sewage will have entered the river while there is still one and a half hours of the ebb tide left to wash it far out to the sea. On the east of the river the present sewers and outfall at the mouth of the river will be utilised; but the sewage will be prevented from backing up the sewers by a tank, and the sewers will be well ventilated and flushed. Provision is made to connect this outfall at some future time with the main outfall on the west by means of a syphon under the river.

THE North Metropolitan Tramways Company notifies its intention of applying to Parliament in the present session, by petition, for leave to insert in its No. 1 Bill, now pending in the House, a clause or clauses authorizing the company to use electricity as a power for moving carriages on portions of its existing or authorized tramways in West Ham, East Ham and Leyton.

THE discussion session of the Manchester Association of Engineers was brought to a close, when Mr. T. L. Daltry read a paper on "Certain Motions used in Weaving." The paper was confined to a description of the various drop-box motions in use, with a narrative of the progress which had been made by different inventors, and in conclusion Mr. Daltry briefly referred to an invention he had himself recently patented. The problem of a good drop-box motion, he said, was no easy one to solve; his aim had been to devise a motion that would run at practically any speed —160 picks, for instance—and slip from one box to any other of four boxes. This, after considerable trouble, he had worked out mainly by the introduction of excentrics, and he claimed that one great merit of his invention was the narrowness of the space which it occupied, whilst with the excentric motion, however high the speed, it did not bang the boxes, but lifted and lowered them quite gently. The chair at the meeting was occupied by the president, Mr. W. H. Bailey, and a vote of thanks to Mr. Daltry, moved by Mr. Thos. Ashbury, C.E., and seconded by Mr. Jas. Walthem, brought the proceedings to a close.

FROM a large number of determinations of the electro-motive force of the currents yielded by zinc-copper and lead-platinum couples in various simple saline solutions, B. C. Damien—*Ann. Chim. Phys.*—finds that the electro-motive force as a rule decreases with the time the couple is immersed. In the case, however, of the zinc-copper couple in solutions of the chlorides, the electro-motive force at first slowly increases. The electro-motive force of the current yielded by zinc-copper couple in a solution of magnesium sulphate is very constant, scarcely varying 0.017 volt during twelve months, and is not appreciably affected by changes either of the strength of the solution or of temperature. By introducing an exterior resistance of 20,000 ohms, the current becomes practically invariable, even when the couple is kept in circuit. The author proposes to employ this couple for the generation of currents of standard strength. The zinc-copper couple yields currents whose electro-motive force is almost identical for members of any class of salts containing a given acid, but varies greatly with a change of acid. Amalgamation of the zinc slightly increases the electro-motive force at first, but it decreases more rapidly than is the case when unamalgamated zinc is employed. The current obtained from a platinum and amalgamated zinc couple in dilute sulphuric acid has its maximum electro-motive force when its solution contains 30 per cent. of acid.